



PHD

**The Representation of an Advanced Service delivered by a Product Service System
A Qualitative Model of Avionics Availability**

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The Representation of an Advanced Service delivered by a Product Service System

A Qualitative Model of Avionics Availability

Nils Elias Thenent

A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Mechanical Engineering

August 2014

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Dedications

To
Maria and Horst

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ABSTRACT

The research presented in this thesis demonstrates the qualitative modelling of an advanced service delivered by a Product Service System (PSS) through the use of a socio-technical systems-based approach. The created model represents dependencies between functions and organisations, and can be used as basis for a quantitative cost model. Focus is on *how* one particular example of advanced services, namely availability is delivered in an industrial context.

Following a review of multi-disciplinary literature and the outline of a suitable methodological approach, a detailed case study of the delivery of an exemplar piece of avionics equipment by BAE Systems and GE Aviation to the UK Royal Air Force is described.

This research shows that the delivery of avionics availability through a PSS has organisational, contractual and functional facets that overlap and influence each other. Multiple qualitative models represent the investigated setting, from a functional and from an organisational perspective. Top-level functions ‘Analysis & Optimisation’, ‘Administration’ and ‘Delivery’ are identified. The results show distinctive similarities and differences between GE Aviation and BAE Systems including a variety of parallel contracts, organisational segmentation and tensions between relationships and contractual obligations.

The findings suggest that understanding a PSS as a socio-technical system is crucial for modelling the PSS and the cost associated with it. This is particularly important when the aim is to continuously control and manage costs rather than the creation of a one-off forecast.

The contribution of this work to the existing body of knowledge, primarily within the domain of cost engineering is twofold: First the creation of qualitative models of an existing PSS delivering avionics availability to show “*what is a PSS*”, and second a methodologically robust approach that takes into account the socio-technical character of PSS to demonstrate “*how to know about PSS*”.

THE STRUCTURE OF THE THESIS

Part I Introduction

Page 1

Presents the background, motivation and scope for this work. Focus is on the trend for availability-based contracts that are delivered by Product Service Systems (PSS) and in particular the Typhoon Availability Service contract that was awarded to BAE Systems. This section specifies the aim of the research which is to provide an approach to integrate *social and technical* aspects in the representation of *an existing PSS* as a foundation for costing advanced services, in particular avionics availability. Furthermore, definitions of core concepts used throughout the work such as systems, qualitative models, advanced services, and cost-related subjects are provided.

Part II Literature Review

Page 17

Offers a critical review of the literature on PSS and cost modelling for PSS at the interface between engineering and management. Gaps and mismatches in the literature are identified that lead to the proposal of a process-based representation of a PSS considering the flow of information and material to represent the context availability is delivered in. Part II concludes by highlighting the need for *understanding* socio-technical systems to generate a meaningful cost estimate of a PSS delivering advanced services.

Part III Research Methodology

Page 59

Represents one of the main contributions of the thesis by structuring and describing ways for *how* to gain knowledge about a PSS. The research methodology relevant to the nature of PSS as a socio-technical system is discussed along with a review on how methodological aspects are addressed in the literature on cost modelling and PSS. Also specifies the selection of standpoints taken in this research considering the philosophical foundation, research type, research strategy and methods for data collection and analysis.

Part IV Empirical Study

Page 107

Describes *what* was done within the research and presents the results. The case study setting centred on the delivery of an exemplar piece of avionics equipment by BAE Systems and GE Aviation to the UK Royal Air Force is described, as well as a detailed account of how data was collected and analysed. Results are then presented from a functional perspective identifying ‘Analysis & Optimisation’, ‘Administration’ and ‘Delivery’ functions and an organisational perspective showing the links between GE Aviation, BAE Systems and the Royal Air Force. The results show distinctive similarities and differences between GE Aviation and BAE Systems relating to a variety of parallel contracts, organisational segmentation and tensions between relationships and contractual obligations.

Part V Discussion

Page 161

Compares the findings from the empirical study with the literature on PSS and cost modelling. It is shown that aspects of the results such as multiple parallel outputs that interfere with each other have also been observed in the literature on service delivery. However, in the literature on cost modelling for PSS these findings find no consideration. Part V clarifies that within a PSS the costs of the delivered outcome should not be modelled as a summation of features of its constituent elements, but as an emergent property of the whole system. In addition, the contribution of the findings to the existing body of literature is outlined, namely the representation of context as a necessity to attribute costs within PSS.

Part VI Conclusion

Page 173

Demonstrates how the research aim was met through the outline and application of a suitable methodological approach to an existing PSS. In this way the relevant system delivering avionics availability was identified and a representation of such system provided. The contribution of this work to the existing body of knowledge is illustrated through specifying “*what is a PSS*” and “*how to know about PSS*”. Finally, the author’s reflections on the research are presented along with suggestions for future work.

AUTHOR'S PUBLICATIONS

Journal papers, accepted

Thenent, Nils Elias; Settanni, Ettore; Parry, Glenn; Goh, Yee Mey; Newnes, Linda B. (2014): Cutting cost in service systems. Are you running with scissors? In *Strategic Change: Special Issue: Servitization* 23 (5-6), pp. 341–357. Available online at 10.1002/jsc.1981.

Settanni, Ettore; Newnes, Linda B.; Thenent, Nils Elias; Parry, Glenn C.; Goh, Yee Mey (2014): A Through-life costing methodology for use in Product-Service-Systems. In *International Journal of Production Economics* 153, pp. 161–177. DOI: 10.1016/j.ijpe.2014.02.016.

Journal papers, submitted

Settanni, Ettore; Thenent, Nils Elias; Newnes, Linda B.; Parry, Glenn; Goh, Yee Mey (2014): Applying 'forgotten' lessons in field reliability data analysis. A case study in defense avionics. Submitted. Submitted to: *IEEE Aerospace & Electronic Systems Magazine*.

Conference papers (peer-reviewed)

Thenent, Nils Elias; Settanni, Ettore; Newnes, Linda B. (2012): Know what you need to know. The role of technological knowledge in product service systems. ESDA2012-82791. In Alain Bernard, Francisco (Paco) Chinesta (Eds.): *The ASME 2012 11th Biennial Conference on Engineering Systems Design and Analysis (ESDA2012)*, vol. 3. Nantes, France, 02.-05.07. ASME (3), pp. 453–464.

Thenent, Nils Elias; Settanni, Ettore; Sandborn, Peter; Newnes, Linda B. (2013): Maintenance within Product Service Systems. Is technical knowledge enough to link performance and cost? In Sari Monto, Miia Pirttilä, Timo Kärri (Eds.): *Maintenance Performance Measurement and Management 2013 conference. MPM*. Lappeenranta, Finland, 12.-13. September. pp. 285–299.

Settanni, Ettore; Thenent, Nils Elias; Newnes, Linda B. (2013): System modeling: a foundation for costing through-life availability provision. In Bernard, A., Rivest, L. and Dutta, D. (Eds.): *Product Lifecycle Management for Society. 10th IFIP WG 5.1 International Conference, PLM 2013*, Nantes, France, July 8-10, 2013, Proceedings: Springer Berlin Heidelberg (IFIP Advances in Information and Communication Technology, 409), pp. 48–57.

Newnes, Linda B.; Settanni, Ettore; Thenent, Nils Elias; Green, Paul (2013): Estimating the Cost of Through-life Availability. In T. Baines, B. Clegg, D. Harrison (Eds.): *Spring Servitization Conference (SSC2013)*. Birmingham: Glasgow Caledonian University, pp. 175–181.

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LIST OF ABBREVIATIONS

ABC	Activity-Based Costing
ATTAC	Availability Transformation: Tornado Aircraft Contracts
AWS	Avionics Workshop
CADMID	Concept, Assessment, Development, Manufacture, In-Service, Disposal
CATA	Costing for Avionic Through-life Availability
CfA	Contracting for Availability
DE&S	Defence Equipment and Support
DRM	Design Research Methodology
FRACAS	Failure Reporting Analysis & Corrective Action System
FRAM	Functional Resonance Analysis Method
IDEF	Integration DEFinition
ITAR	International Traffic in Arms Regulations
KPI	Key Performance Indicator
LCC	Life Cycle Costing
LRU	Line Replaceable Unit
MHDD	Multifunctional Head Down Display
MoD	Ministry of Defence (UK)
MRO	Maintenance, Repair, Overhaul
MTBF	Mean Time Between Failure
NETMA	NATO Eurofighter and Tornado Management Agency
NFF	No Fault Found
OEM	Original Equipment Manufacturer
OSCM	Operations and Supply Chain Management
PCN	Process Chain Network
PPR	Product, Process, Resource
PSS	Product Service System
PSS OI	Product Service System of Interest
RAF	Royal Air Force
RFP	Request For Proposal
RTAT	Repair Turnaround Time
SBS	Service Breakdown Structure
SD logic	Service Dominant logic
SOI	System Of Interest
SSM	Soft Systems Methodology
TAS	Typhoon Availability Service
UAS	Unmanned Air System
WBS	Work Breakdown Structure

PART I: INTRODUCTION

*I'm standing at the crossroads
There are many roads to take
But I stand here so silently
For fear of a mistake.*

*One path leads to paradise
One path leads to pain
One path leads to freedom
They all look the same.*

Calvin Russell (1991)

1 Background

In this research a particular type of support arrangements for high-value technical systems, such as military aircraft is investigated. Focus is placed on how such arrangements can and should be analysed, for example for cost estimation and cost control purposes. This work proposes a *qualitative* description of the delivery of availability for the Eurofighter Typhoon Multifunctional Head-Down Display (MHDD) as a foundation for a *quantitative* system and cost model of the PSS.

1.1 Contracting for availability

An emerging trend in defence and aerospace is the move from manufacturing and selling products to providing the availability of a product-related function based on long-term contractual agreements where former manufacturers are required to

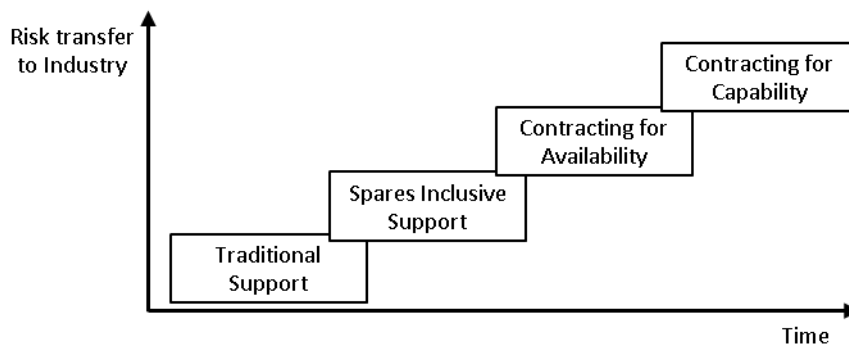


Figure 1 'Staircase' transformation for the UK Defence Logistic Organisation (Source: Elford, 2011).

act as service providers. Such contracts may reflect a variety of business models, depending on which product-related functionality is provided (Meier *et al.*, 2010a).

In the defence supply chain, an availability-oriented business model, associated with availability-based contracts, is regarded as a valuable way to incentivise Original Equipment Manufacturers (OEMs) to offer more reliable equipment compared to the traditional “product and support” business model (Caldwell and Settle, 2011). This move towards the provision of product-related functionality is illustrated schematically in Figure 1 with specific reference to the UK Ministry of Defence (MoD) Defence Logistics Transformation.

Under “Contracting for Availability” (CfA) arrangements in the defence sector, industry is paid for equipment that is ‘usable’ by the customer, that is, in an operable and committable state, or deployable. An example is an aircraft on the apron, in a fit state for the air force personnel to fly it (BAE Systems, 2009). In principle, under an availability contract value is delivered “in use” (Ng *et al.*, 2011a; Baines *et al.*, 2007).

As a consequence, the concern of an OEM as a service provider shifts towards all means that are required to ensure the availability of the product related function by taking responsibility for business processes of the customer (Meier *et al.*, 2010a). Accordingly, there is a need to consider the operating and support phases during service design to ensure suitability of the support system for the equipment usage (Meier *et al.*, 2011; Newnes *et al.*, 2011), as shown in Figure 2. This representation builds on a commonly used illustration for the defence procurement and consists

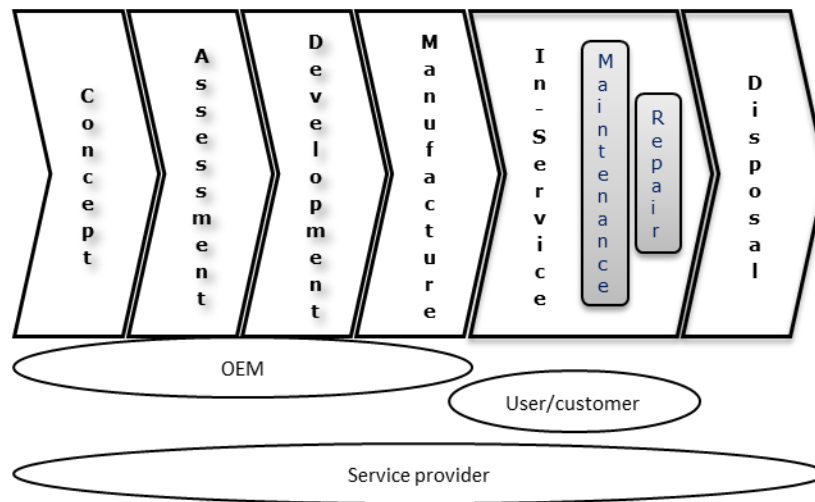


Figure 2 Generic CADMID life-cycle showing the areas of responsibility of an OEM, the user (or customer) and a Service provider.

of a sequence of phases through which a durable product progresses over time from concept through to disposal (see for example Cheung *et al.*, 2009, p. 173).

In contrast to the sequential, and product-centred view illustrated in Figure 2, recent literature has suggested the adoption of a broader perspective where a system of interconnected and interdependent activities undertaken by a diverse network of stakeholders is required to achieve a common purpose, i.e. the delivery of the desired outcome. The boundaries of such system are referred to as “*through-life service enterprise*” in the academic literature (Purchase *et al.*, 2011b). Within these boundaries, a socio-technical system, commonly referred to as Product Service System (PSS) operates to deliver services that are critical to a customer’s core processes, as for example in availability contracts (Baines and Lightfoot, 2013, pp. 5–7; Tukker and Tischner, 2006). The concept of PSS is central to this research and is discussed in more depth in section 6.3 Advanced services.

Organizations such as BAE Systems that are in the process of moving from a product- to a service-based business model (e.g. by offering long-term availability for the engineering systems they manufacture) have a long history as product-focused manufacturers. This business model transformation from manufacturing to providing services presents them with, multiple challenges, e.g. in transforming processes, culture and relationships with customers (Purchase *et al.*, 2011a, pp. 25–26). For example, according to Parry (2010), discussing the ATTAC (Availability

Transformation: Tornado Aircraft Contracts) contract, the transformation towards integrated product service offerings was not sufficiently reflected in the prime contractor's business culture. Within the ATTAC contract with the MoD BAE Systems provides the availability of the Tornado GR4 fleet for the RAF (Parry *et al.*, 2011b; Mills *et al.*, 2009).

Apart from ATTAC and the TAS contract that was awarded in 2009 to BAE System, the MoD has similar contracts in place for other platforms. For example, in 2013 a £258 million deal was signed between the UK MoD and AgustaWestland to continue the availability-based maintenance of the fleet of Sea King helicopters flown by the RAF and the Royal Navy (Hoyle, 2013a). In the commercial aerospace industry Rolls-Royce is acknowledged as one of the pioneering companies for such offerings and is now referred to as an exemplar success history for the British industry (The Economist, Jul 30th 2011). Their "Power by the Hour" offering provide the airline operator with fixed engine maintenance costs, over an extended period of time, while at the same time guaranteeing availability of the engines (Bagnall *et al.*, 2000; Baines *et al.*, 2009a).

1.2 *The challenge of cost estimation for availability*

A desire for cost savings is identified by key executives as leading customers to adopt service offerings rather than buying and maintaining high values assets (Aston Business School, 2013). Yet, statements suggesting cost reductions of 25-30% for customers of such services appear to be based upon subjective impressions and many key questions are not addressed such as 'which cost is meant?', 'how are costs determined?' and 'for what purpose was the cost computed?'. Concern has been expressed that claims related to the cost-effectiveness of these advanced service arrangements, which may eventually result in their practical implementation, are often made in the absence of sound business model analyses (GAO, 2008). In some cases, such as the Pratt & Whitney's F117 engines powering the US Air Force's fleet of C-17A airlifters there has been a move back to more a traditional approach to maintenance in the hope that more competition in the support contract bidding phase drives prices down (Trimble, 2013). In addition, statements on cost savings can be particularly misleading in times of pressure on defence budgets, because apparently straightforward initiatives for saving money may prove ineffective since they can

compromise the ability to deliver capability when needed. In particular cuts in training and maintenance, reduction of force structure and cancellations of equipment programs which are already under way may eventually drive up an asset's unit cost (Chinn, 2013). For example, the potential loss of competent personnel which needs to be compensated for can incur further expenditures, as in the case of maritime surveillance (Hoyle, 2012).

Cost engineering practices have tended to focus on how much product systems cost but rarely on *why* a product system will cost a certain amount (Dean, 1993). Eventually, costs estimates are produced that rely on the information available, rather than on considering why the costs occurred and acting on their causes (Naylor *et al.*, 2001). At the heart of the 'should cost' estimating process that has long characterised the product-centred 'sell and support' business model lies the idea that an accurate cost estimate can (and should) be obtained in the absence of an understanding of the product, the methods of manufacture/process and relationships between processes (Roy, 2003; International Society of Parametric Analysts, 2008). Such view is challenged when it comes to the delivery of availability through PSS. An OEM operating under availability-based contracts is concerned with the ability to operate at a profit, and therefore requires an understanding of the cost of supporting its customers' core business processes by providing agreed levels of product-related functionality through the equipment's useful life (Meier *et al.*, 2010a).

The above suggests that estimating the cost of avionics availability is a challenge that originates from the deliverable not being a product, but the integrated delivery of services and products through a socio-technical system, the PSS. Depending on the specific agreement for the provision of a PSS business processes such as production processes and the responsibility to coordinate the delivery network of sub-suppliers can shift from the customer to the PSS provider (Meier *et al.*, 2010a; Meier *et al.*, 2010b). As a result additional risks are placed on the PSS provider (Hypko *et al.*, 2010). This operational dynamic is profoundly different compared to the traditional business model, where the manufacturer or system integrator was able to transfer for example, almost all of the risk associated with operating the product, driven by reliability, maintainability, and in-use to the customer. Availability contracting no longer allows such transfer of risk, or at least tries to mitigate it (Jacopino, 2007). Rather, the provision of availability through a

PSS relies on close interaction and shared resources of the provider and the customer, as the boundaries between the two become more “fluid” (Ng *et al.*, 2011a). However, in the defence sector the degree of operational risk a contractor can assume may be actually limited due to the nature of military operations (Doerr *et al.*, 2005). Things may be further complicated by the fact that the customer – e.g. the MoD – is not even the end user; instead the aircraft is operated by another organisation, in this research the RAF.

The relationship of the availability provider with the customer and the user plays a significant role for the successful fulfilment of the contract, as depending on the user’s behaviour the provider may or may not be able to perform as required. Maintenance and repair habits and processes have an important impact on meeting the availability targets and on imposing requests on the provider’s resources (Jazouli and Sandborn, 2011). In this context the relationship with the suppliers becomes crucial. In order to remain responsive towards the customer, and to ensure that the required and requested performance is delivered, strategic relationships between the provider and its suppliers are often recommended. According to Purchase *et al.* (2011b, p. 21) one of the advantages of a through-life service enterprise such as the ATTAC is that it allows disparate resources from multiple organizations to be pulled together to pursue value for multiple stakeholders, including customers, employees and shareholders. If this is not achievable in practice, the provider has to deal with important processes, for example the repair of components while having only limited visibility of frontline usage, and its supplier may in turn have no visibility of the customer demand. Such situation is seen as an issue in the successful operation of availability contracts (Datta and Roy, 2011).

2 Motivation for this research

It is still an open question how to give adequate visibility to the processes involved in the delivery of the final outcome (Ng and Nudurupati, 2010; Datta and Roy, 2011; Batista *et al.*, 2008). Since PSS are socio-technical systems, these processes are prone to local adaption and pragmatism by managers tasked to deliver local goals, but whose actions can ultimately lead to the breakdown of the whole delivery system. Through the adaption of local habits (Vaughan, 1997; Snook, 2002) informal processes develop that no longer correspond to the –well intended, but static – formulation of official, or formal processes (Christensen and

Kaufman, 2009). Hence, maintaining a dynamic common understanding of these local behaviours is imperative. Means to facilitate communication, such as visualisation in the form of pictures and diagrams (Cooke, 1994) can support the achievement of a shared understanding among a larger group about the same problem domain (Conklin, 2006; Bell and Badiru, 1993; Snyder *et al.*, 1992). As such visualisation, for example qualitative models can increase the value of available information by defining common meaning of information among different stakeholders (Jakubik, 2011). One way to visualise the network of activities within a PSS is a qualitative model based on business process mapping.

In this work a *qualitative* model of the PSS delivering availability of the Eurofighter Typhoon Multi-functional Head Down Display (MHDD) is created to provide the foundation for a *defensible* quantitative proof of concept cost model of avionics availability. A “*defensible*” model, means that the method of inquiry is appropriate for the phenomenon of interest (Wilson, 2001, p. 5). The research is embedded in the “Costing for Avionic Through-life Availability” (CATA) research project. CATA is motivated by a general trend for availability-based contracts and in particular the £430m five-year Typhoon Availability Service (TAS) contract that was awarded to BAE Systems in 2009. TAS was set-up between BAE Systems and the UK Ministry of Defence (MoD) Defence Equipment and Support (DE&S) organisation in close cooperation with the Royal Air Force (RAF) to ensure the UK’s Typhoon fleet is available and meets operational requirements (BAE Systems, 2009, p. 70). The aim of CATA is a proof of concept of a cost model that supports informed decision making in availability-type contracts.

Figure 3 shows the four strands that contribute to the CATA proof of concept cost model. The qualitative model, subject of this work, is shown in a red frame. It is linked to the quantitative modelling by providing the underlying structure of the model. This structure is reflected in the ‘relevant’ system that delivers the Eurofighter Typhoon MHDD availability as the constituting elements and their relationships. In this way the qualitative model, rather than the ‘real’ PSS, becomes the object of analysis of the quantitative model (Checkland and Scholes, 1999). Therefore, from an application perspective, the qualitative representation needs to provide a structure that is compatible to the quantitative model. In addition to the qualitative model of the PSS, the contribution of this work is a methodological

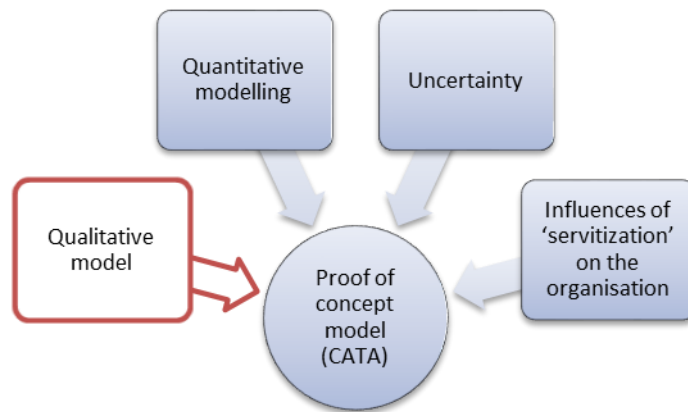


Figure 3 This work in relation to the CATA project.

discussion why the chosen method of inquiry is appropriate to the phenomenon under investigation.

Also shown in Figure 3 is the ‘uncertainty’ strand where approaches to modelling uncertainty and their integration into the quantitative model are investigated. The fourth CATA strand is represented by the ‘Influences of servitization on the organisation’ contribution that investigates how organisations that are involved in the delivery of availability are affected by the corresponding change in responsibilities.

3 Research aim & objectives

Being embedded in the CATA project this work contributes to the overall CATA aim to create a proof of concept of a cost model that is methodologically equipped to deal with long-term availability-type contracts.

3.1 Aim

The aim of this work is to provide an approach to integrate *social and technical* aspects in the representation of *an existing PSS* as a foundation for costing advanced services, in particular avionics availability.

3.2 Objectives

1. To identify how to *conceptually* integrate products and services.
2. To identify characteristics of PSS as socio-technical systems.

3. To outline a suitable methodological approach to investigate and represent the characteristics of PSS as a socio-technical system.
4. To apply the outlined approach to an existing PSS that delivers avionics availability to identify:
 - a. The *relevant* system elements;
 - b. The relationships between the elements;
 - c. The system boundaries.
5. To represent the PSS delivering avionics availability in a qualitative model that can be used as a foundation for costing advanced services.

4 Scope

While the aim of CATA is a through-life cost modelling approach, this work is restricted to the TAS contract for the in-service phase of the Eurofighter Typhoon program. More information on the Eurofighter Typhoon can be found in Jackson (2010), Eurofighter Jagdflugzeug GmbH (2013) and Ashford *et al.* (1996).

Furthermore, the CATA research and hence this work is limited to an exemplar element of the Eurofighter Typhoon avionics suite, namely the MHDD being delivered by GE Aviation under the responsibility of BAE Systems, as shown in the red frame in Figure 4. The radar and Defensive Aid Sub-System (RDASS), depicted in parallel to TAS in Figure 4 represents a separate contract (Defense Industry Daily, 2014).

Because ‘service’ is a term that is used with multiple meanings (Baines *et al.*,

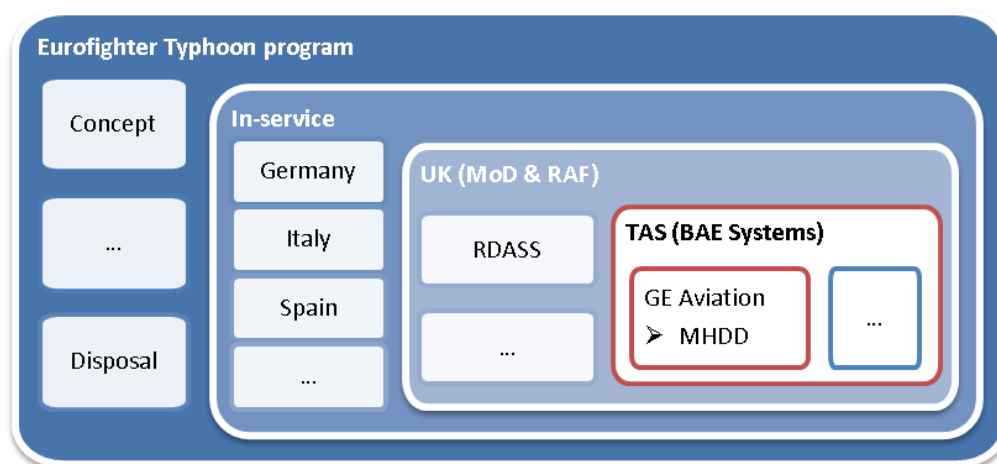


Figure 4 Scope of this research within the Eurofighter Typhoon program.

2009b) the scope of this research is limited to the provision of ‘advanced services’ (see definition in section 6.3) in an industrial context.

5 Contribution

The contribution of this work is primarily within the domain of cost engineering. The expected benefit is to broaden existing concepts and practices which are largely centred on knowledge about individual instances of hardware. This research provides an approach to achieve the necessary understanding of a PSS for rigorous and defensible PSS modelling. This is largely achieved by introducing concepts and arguments from other disciplines, most significantly from social theory.

The contribution of this work to the existing body of knowledge is twofold in terms of defining “*what is a PSS*”, as well as providing an approach that enables modellers to answer the question “*How to know about PSS?*”:

1. To demonstrate that the delivery of avionics availability through a PSS has organisational, contractual and functional facets that overlap and influence each other.
2. To outline an approach that takes into account the socio-technical character of PSS to investigate social phenomena within PSS.

The approach followed here builds on a careful selection of research methodology. As such this work seeks to contribute to the debate about the nature of PSS as socio-technical systems by structuring and clarifying methodological aspects that are necessary to gain knowledge about PSS, and how to analyse the collected data. The methodological approach outlined in the thesis and the representation techniques chosen are considered suitable for contexts other than the case investigated in this work. These can include different industrial settings beyond defence aerospace, and different phases of a product life cycle within a PSS other than the usage, such as design and manufacture.

6 Terminology

Because this work is based on a range of different disciplines, such as engineering, the social sciences and management, this section provides an overview of core concept definitions that underpin this research. These definitions are not meant to

give an exhaustive review of the respective subject or discipline, but aim at reducing terminological ambiguity and provide a clear and concise summary of the meanings of the terms used within this research.

6.1 Systems

This paragraph outlines the main characteristics of ‘systems’ and related terminology. ‘Systems’ as a recurring term can easily become the subject of ambiguous interpretations, in particular an interpretation of systems as ‘product system’ is common in cost engineering, see for example Valerdi (2011). In contrast, Checkland and Scholes (1999, pp. A10) refer to ‘systems’ not as something that exists in the ‘real’ world, but rather as a construct that can be employed to think about and to make sense of the “*very complex, problematic, mysterious*” world. For a comprehensive review of the literature on socio-technical and large technological systems the interested reader is referred to Bartolomei *et al.* (2012). Another aspect of systems highlighted by Burge (2010) is that they are dynamic and evolve over time. An understanding can therefore only be acquired when the system is examined reflecting its behaviour over time. This includes consciousness about the system’s life cycle as reflected in the standard BS ISO/IEC, 2002.

By comparing the definition of a system given by different authors such as Burge (2010), Wasson (2006) and Blanchard (2008) the common characteristics of systems are identified as:

- A system consists of multiple elements (or components);
- These elements interact with each other;
- A system has a purpose.

In addition to these “*key elements*” of a system (Burge, 2010) another characteristic is fundamental to how ‘systems’ are understood in this research:

It is not possible to deduce the properties and behaviour of the whole system from the properties and behaviour of its constituting elements in isolation (Burge, 2010).

This has significant implications on the investigation of a system and its components, as it excludes the possibility of capturing and superimposing the individual components’ characteristics to successfully describe the system. Only when brought together and interacting with each other the so called emerging

properties of a system arise (Burge, 2010, p. 5; Dekker, 2011). These are not observable, without considering the system as a whole. They may not even be predictable when looking at the complete system, as their occurrence is based upon relationships between the components that may not be known, or knowable (Dekker, 2011).

Related to the concept of ‘systems’ is the notion of ‘*process*’ as a repetitive system for producing services or products that includes machines, people, software and procedures (Bohn, 1994, p. 62). As such, a process is a series of interlinked activities for the achievement of a specific objective (Hansen and Mowen, 2003, pp. 27–164). Hence, *business processes* are a combination of activities within an organisation (or multiple organisations, e.g. an enterprise) that are structured to produce the desired result (Aguilar-Saven, 2004, p. 129).

6.2 *Qualitative models*

Models are representations of the relevant characteristics of a phenomenon of interest (Peterson, 1981, p. 1). A qualitative model relies on non-numerical descriptions of characteristics of the phenomenon that is modelled. As such qualitative models are opposed to quantitative models that represent the phenomenon in numerical terms. A more detailed discussion on ‘models’ can be found in Part III, section 5.3 Models.

Process models can be quantitative or qualitative representations of activities, their relationships inputs and outputs. In particular business process models can support a common understanding and analysis to provide a comprehensive understanding of a interrelated activities, for example within an enterprise (Aguilar-Saven, 2004, p. 129). Process models are discussed in further detail in Part III, Research Methodology, section 5.3.2

6.3 *Advanced services*

Baines *et al.* (2009b) point out that the meaning term ‘service’ can be highly context-specific. This work endorses the definition of advanced services by Baines and Lightfoot (2013, p. 5):

“Advanced services are a special case in servitization. Sometimes known as outcome, capability or availability contracts, here the manufacturer delivers

services (coupled with incentivized contracting mechanisms) that are critical to their customers' core business processes."

While production systems deliver products, Product Service Systems (PSS) deliver advanced services (Baines and Lightfoot, 2013, pp. 6–7).

6.4 Costs, price, expenditure

As pointed out by Field *et al.* (2007) the meaningful use of cost information is impeded by terminological ambiguity around the notion of cost. To overcome this ambiguity, this section establishes clear distinctions between the concepts of costs, price and expenditure rather than using these terms as synonyms.

In this research, *costs* are seen as a “*measure of resource consumption to the demand for jobs to be done*” (Emblemsvåg, 2003, p. 28), and include the resources for the sustainment and provision of the required capacities (Mensen, 2003, p. 700). This viewpoint is consistent with the interpretation of money as a meta-language to express the flow of goods and services through economic activities performed by organisations (van der Merwe, 2007b).

What the word ‘*costing*’ in terms such as ‘Through-life costing’ implies is typically not defined explicitly. Within the engineering community, cost is viewed as “*a relatively simple thing*”, that is, something that can be resolved in the course of a design or development activity, and hence not worth being the centre of the engineering effort (Field *et al.*, 2007). It can be deduced that ‘costing’ is the action of determining, typically in a quantitative way, the monetary worth of ‘*cost objects*’, typically products or services that can be identified within an organization (Hansen and Mowen, 2003; van der Merwe, 2007b).

A particular approach to costing is *Activity-Based Costing (ABC)* in which costs are attributed by tracing them to activities first and then to cost objects (Hansen and Mowen, 2003, p. 991). Central to ABC are the relationships between cost objects, activities and resources where *resources* are measured as cost and represent everything the organisation uses for its operation (Emblemsvåg, 2003, p. 100). Following Emblemsvåg (2003, p. 100) cost objects, activities and resources interact as follows: “*The cost objects consume activities, which in turn consume resources. Thus, ABC is a two-stage costing system.*”

Commonly used as a synonym for cost, *price* is another term that has the potential to cause ambiguity. For example, Ellram (1996, p. 15) describes an organisation's efforts to ensure it is "*paying a fair price*" when purchasing items as the goal of *cost analysis*. In this thesis, 'price' is considered as "*the cash or cash equivalent value sacrificed for goods and services that are expected to bring a current or future benefit to the organisation*", which is the definition of cost given by Hansen and Mowen (2003, p. 32). From this definition it becomes evident that underneath the concept of price is a market transaction that manifests the monetary value of an exchange of goods or services. Once such transaction takes place an amount of money is leaving the boundaries of an organisation over a certain period of time (e.g., one year). This amount of money is called '*expenditures*'.

The difference between cost and expenditure is that the concept of *cost* is motivated by the need for a measure of how efficiently the resources within the organization are utilised – not just that of giving an account of the money spent over a period of time for whatever reason. As Stewart (1982) puts it, the purpose of a cost estimate is to assure maximum productivity in accomplishing a job by efficiently and effectively managing the job itself.

6.5 Cost modelling

Sandborn (2013) defines *cost modelling* as an a priori analysis that maps the characteristic features of a product, the conditions for its manufacture and for its use into a forecast of monetary expenditures, irrespective from whom the monetary resources will be required (the provider, the customer, etc.). Although it is often claimed that the origin of cost modelling is "always" with data analysis or data mining, the generation of a cost estimate eventually requires the application of a combination of logic, common sense, skill, experience, and judgement (Stewart, 1982). Hence, cost modelling is a knowledge intensive activity (Curran *et al.*, 2004).

One of the domains concerned with cost modelling is *cost engineering*. Cost engineering relies on engineering judgement, experience and techniques for "*cost estimating, cost control, business planning and management science, profitability analysis, project management and planning and scheduling*" (Xu *et al.*, 2012, p. 1). Cost engineering can be "*used for predicting/forecasting/estimating the cost*" of activities or outputs (Xu *et al.*, 2012, p. 1). As such, cost engineers are concerned with the

planning and monitoring or investment projects to find a balance between quality, time and cost requirements (Morrill, 2014). The final aim of cost engineering is normally not to know 'the cost' but to gain knowledge about "*where to reduce cost and if customers can afford the product/ project cost*" (Xu *et al.*, 2012, p. 4).

A *cost estimate* is an opinion based on analysis and judgement of the cost of a product, system, or structure (Fabrycky and Blanchard, 1991).

Cost estimating is the process of predicting or forecasting the cost of a work activity or output by interpreting historical data (Curran *et al.*, 2004).

Life cycle costing (LCC) focuses on cost analysis of alternative suppliers of investment goods. The scope of an LCC analysis comprises the initial and follow-up costs for operation, maintenance and disposal of the overall life cycle of investment goods with the aim to select the most cost-effective alternative in the long-term (Geissdörfer *et al.*, 2009, p. 695).

PART II: LITERATURE REVIEW

*Well I don't know why I came here tonight,
I got the feeling that something ain't right,
I'm so scared in case I fall off my chair,
And I'm wondering how I'll get down the stairs,
Clowns to the left of me,
Jokers to the right, here I am,
Stuck in the middle with you*

Stealers Wheel (1972)

The literature review is a critical examination of publications relating to the phenomenon of interest covering existing research and including the relevant theoretical concepts (Bryman, 2012, p. 14). Additionally, the review is intended to identify gaps in the existing body of knowledge to formulate more insightful questions for future research (Webster and Watson, 2002, p. xix; Yin, 2009, p. 14). The literature of interest in this chapter concerns three main topics, “Product Service Systems”, “Cost Estimation”, and on a more theoretical level “Systems”. To keep focus, the literature of interest is mostly at the interface between the Engineering and Management fields, with an emphasis on applications to the aviation maintenance industry. Within the review in sections 2 and 3, at the end of each subsection the most relevant findings about cost estimation and PSS are summarised. These findings and mismatches between the findings are shown in section 4 where the need for research is identified.

1 Approach

The public domain literature on the topics of interest was explored mainly by keyword search in major academic publisher's online databases such as EBSCO, as well as librarian services at the University of Bath. Keyword searches around the areas Product Service Systems, Cost Estimation and Systems, complemented by more details, such as "Avionics", "Maintenance", and "Aerospace" provided pathways to insights into specific applications. In addition to keyword searches, cross referencing between scientific papers and books provided understanding of lines of argumentation. Information on industrial practices and business decisions was obtained from specialised magazines and websites that are renowned in the field of aviation, mainly "Aviation Week and Space Technology" and "Flightglobal".

To support the efficient extraction, organization, retention and analysis of the relevant contents in the documents retrieved, a knowledge base (in the form of a central server-based directory where documents are stored) was created and maintained, with the aid of the reference management software Citavi (www.citavi.com). The knowledgebase has been built through a collaborative approach between the researchers involved in the CATA project at the University of Bath.

The use of that knowledgebase containing all reviewed documents has supported and eased the traceability and usability of findings and ideas. While this is not the

Table 1 References within the CATA project's Citavi knowledgebase by types (02.05.2014).

Reference type	Quantity
Journal article	615
Book	150
Book, edited	48
Conference proceedings	84
Contribution (to edited book and conference proceedings)	237
Unpublished work	91
Standard	8
Press release	4
Internet document	47
Statute or regulation	4
News agency report	2
Thesis	16

place for an introduction to Citavi, some of its properties that greatly supported the literature review are outlined below. Table 1 shows the number of the most relevant reference types that constitute the whole CATA project's Citavi knowledgebase.

The main feature of the knowledge base is the assignment of personalised categories and keywords to entire documents as well as to excerpts from those documents, which constitute the relevant knowledge items in the knowledgebase. Since the knowledgebase was actively used and populated by the author and one other researcher from the CATA project a categorisation structure was agreed that enabled the retrieval of documents and knowledge items by both users. Top-level categories each containing multiple sub-categories were created that reflected the main topics of interest. The first top-level category was for CATA-internal documentation, such as minutes and presentations, the second for the general categorisation of academic and non-academic literature, and the third for each individual researcher to create his or her own categorisation.

Table 2 General categories of the knowledgebase (note that one reference can be assigned to more than one category) (02.05.2014).

Category	Quantity
Lessons learned	43
Servitization	136
Contracting for availability	117
Enterprise / supply chain	88
Uncertainty	141
Risk	52
Costing & cost estimation	419
Modelling techniques	373
Technology concepts	82
Availability	120
Performance	121
Design	149
Avionics	152
Aircraft	228
Maintenance & repair	360
A/C subsystems, not avionics	51
Microelectronics, not avionics	60
Other products	163
Military and defence	221
Regulations & norms	25
Knowledge	221
Complexity	43
Systems & system thinking	99

Every document was assigned to at least one, possibly more categories. Table 2 shows the sub-categories of the top-level category of the academic and non-academic literature. Throughout the research categories were added, to reflect the evolving understanding and focus of the research. In case of the general categories, no further sub-categories were introduced to facilitate the interpretation of main topics across the CATA project team.

Figure 5 shows the more specialised categories created by the author for the specific focus of the research presented in this thesis. They reflect the range of literature reviewed including engineering topics such as maintainability and condition monitoring, as well as concepts of knowledge, and a detailed breakdown on research methodology.

In addition to categories, each reference can be assigned with keywords in the Citavi knowledgebase by the user. Within the CATA knowledgebase more than 3000 different keywords were assigned, each reference at least one.

A Citavi feature that supported the traceability of literature is the extraction and categorisation of text excerpts from references. These excerpts are called “Knowledge Items” in Citavi and can be categorised and assigned with keywords

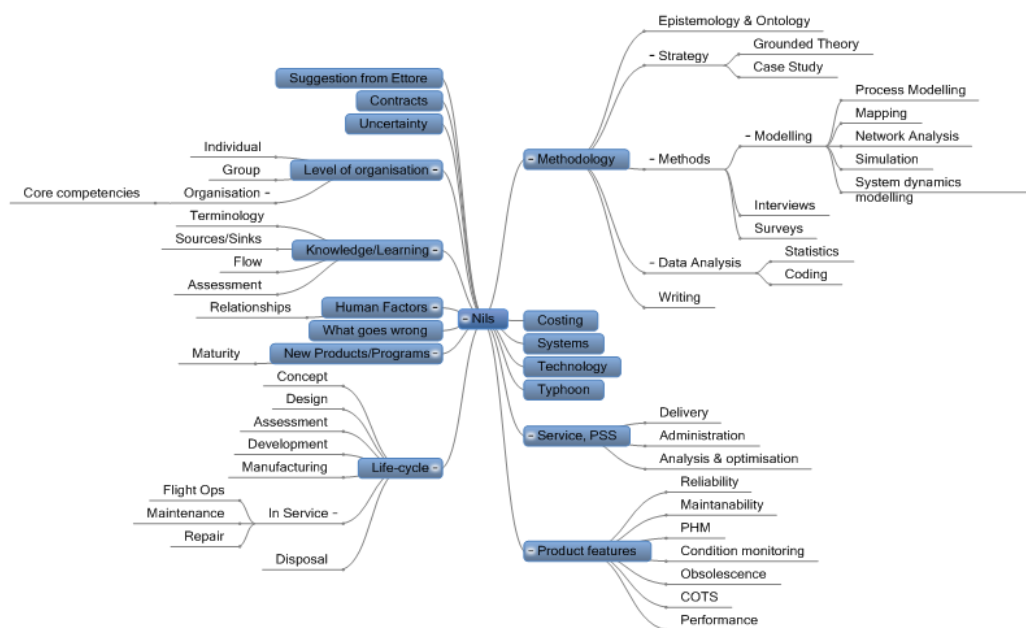


Figure 5 Author's knowledgebase categories (02.05.2014).

individually. In this way, when searching for a particular subject, for example 'Availability', all excerpts that have previously been categorised to 'Availability' can be retrieved independently of the categorisation of the source document. Through the combination of multiple filters, combining keywords and categories relevant literature could quickly be narrowed down and previous ideas could easily be retrieved. At the time of writing this thesis the CATA knowledgebase contained more than 4000 knowledge items.

2 Product Service Systems

Product Service Systems (PSS) are commonly associated with 'servitization', a term that has gained prevalence through the work of Vargo and Lusch (2004) in the field of marketing. Servitization reflects a trend where organisations seek competitive advantage by selling integrated product service offerings that deliver a desired outcome to the customer (Baines *et al.*, 2007). These solutions based on long-term customer provider relationships are delivered through PSS (Martinez *et al.*, 2010, p. 451) that are a result of "*the interaction between different actors and technological elements*" (Morelli, 2002, p. 7). Therefore, when dealing with PSS, social *and* technological factors need to be taken into account.

A special case in servitization is where former manufacturers offer services that are critical to their customers' core business processes through incentivised contracting mechanisms such as availability or performance-based contracts (Baines and Lightfoot, 2013). For these providers servitization involves innovation of their internal capabilities in operations, and the service delivery system is just as important as the service offering itself (Baines and Lightfoot, 2013, p. 5). Since the CATA project and this thesis are concerned with an availability-type delivery, advanced services are particularly relevant for this work. Section 2 provides theoretical insight into such a service delivery system from a 'system thinking' perspective, highlighting aspects that may be a challenge for costing advanced services.

2.1 Fundamentals

The concept of PSS, delivering advanced services such as availability, allows a range of possible service deliverables differing for the degree to which the customer is involved in the achievement of the desired result. Figure 6 illustrates

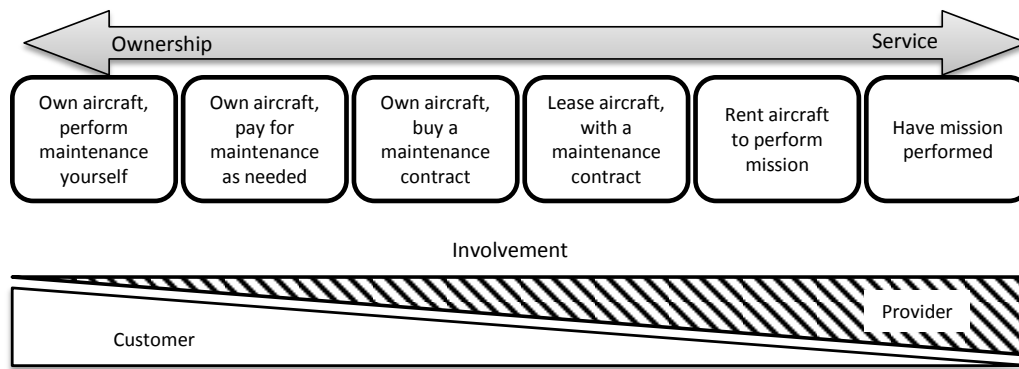


Figure 6 Example of PSS range for an aircraft (adapted from Sandborn, 2013; Datta and Roy, 2010).

the range of deliverables between an aircraft (product) and a successful mission (full service). Proceeding from left to right, the shift in responsibility towards the delivery of value 'in use' for the customer leads to an increased concern of the provider to integrate the intangible features of the delivery with product-related characteristics. In this course, the ownership of the product may also shift from the customer to the provider (Mont, 2002).

The provision of availability in a military aviation context can be placed in the middle of Figure 6: The customer owns the asset and contracts out maintenance through long term service support contracts with performance guarantees. Given the importance of the physical PSS core; and the business-to-business relation between PSS manufacturers and customer, this setting is sometimes referred to as a '*technical*' PSS (Aurich *et al.*, 2006).

2.1.1 Seeing Service Systems as 'systems'

Although the concept of a 'system' is somehow embedded in the concept of PSS, it has been highlighted that most approaches, especially in the engineering domain, overlook the qualification of PSS as 'systems' (Cavalieri and Pezzotta, 2012). Such a qualification carries its challenges from a conceptual perspective. Wang *et al.* (2013) suggest that a PSS is a special case of 'service systems'. According to the authors, *service systems* exhibit distinguishing features such as a network infrastructure; a substance (the types of which include material, human/animal, energy and knowledge) flowing over such an infrastructure; and a protocol for the

management (coordination, leading, planning and control) of both the structure and the substance.

Central to the concept of a service system is that it enables the customer to attain a result, or beneficial outcome, through a combination of activities and resources, including assets, to which both the service provider and the customer contribute (Ng *et al.*, 2011b). However, when it comes to the offering of advanced services (e.g., equipment availability) the specific literature on PSS tends to focus on the technical components of the PSS. For example, Meier *et al.* (2010b) focus on the hardware-software interaction in managing decentralised operational responsibilities of a provider of CNC machines support services. Löfstrand *et al.* (2012) focus on hardware failure to model the completion of support tasks within a service support system delivering product functional availability.

By contrast, at a more general level it is recognised that it is not possible to deduce the properties and behaviour of the whole system from the properties and behaviour of its constituting elements in isolation (Burge, 2010). This has significant implications for the investigation of a system and its components as it excludes the possibility of capturing and superimposing individual components' characteristics to successfully describe the total system. Only when brought together and interacting with each other do emergent properties arise (Burge, 2010; Dekker, 2011). These may not even be predictable when looking at the complete system as their occurrence is based upon relationships between the components that may not be known, or knowable (Dekker, 2011). Some of these relationships may be intended or not, they may however only exist temporarily and can therefore be difficult or impossible to comprehend (Perrow, 1984). Hence, an understanding can only be acquired when the system is examined over time, and any investigation of a system can only provide a snapshot in time. Although without explicit reference to systems theory, a similar principle has been highlighted with reference to equipment costs, through the concept of 'cost image' as proposed by Lindholm and Suomala (2007).

Finding 2.1.1: PSS are service systems that achieve their outcome through resources being employed in activities. Emergent properties of systems can only be observed when investigating the whole system, and not the constituting elements in isolation.

2.1.2 Service systems are socio-technical systems

Service systems are socio-technical systems due to the coexistence of physical and human components. The coexistence of these components is acknowledged in Systems Engineering frameworks (Bartolomei *et al.*, 2012). However, Systems Engineering aims at deriving solutions by applying techniques to a well-defined problem. By contrast, a defensible intellectual process of thinking about a socio-technical system has to start by defining, not a problem but a situation that is problematic (Wilson, 2001). Only a few authors have explicitly suggested that service systems should be approached as social construction. In particular, Morelli (2002) suggests that the technical representation of a PSS should contain indications about potential functions, interaction between actors and functionalities and flows of events.

Flood and Carson (1988) point out that systems in general are objects as perceived by people, and highlight the difficulties arising when one tries to distinguish a system from its surroundings. With regards to socio-technical systems in particular, it has been highlighted that there is no reasonable prospect of gaining complete knowledge about the whole system (Hollnagel, 2012). Hence, local decision-making is always based on incomplete knowledge about the whole system and actions undertaken to optimally fulfil locally visible goals are prone to manifest in global system tensions or even failure (Dekker, 2011; Snook, 2002). Such situation is exacerbated by the observation made by Hollnagel (2012, p. 22) that within socio-technical systems the construction of direct cause-and-effect relationship is problematic as relations and dependencies evolve over time.

Dekker (2011, p. 139) highlights that socio-technical systems are open systems and therefore, when analysing a socio-technical system, there is a difficulty of clearly identifying what is actually affected by an action and what is not. Hence, the boundaries between the “*system of interest*” (SOI) (Wasson, 2006) and the exogenous components that affect or are affected by the system (that is, the environment) should be determined by the purpose of the system description (what shall be examined and why), not by the system itself.

Drawing the system boundaries allows a distinction between what are deemed uncontrollable external events (originating with the environment) and controllable internal events. The former are the subject of “*forecasting*” whilst the latter are the

subject of “*decision making*” (Makridakis *et al.*, 1998). In the context of ‘servitization’ the boundary defining lens is the *enterprise*, which “*imposes a holistic management or research perspective on a complex system of interconnected and interdependent activities undertaken by a diverse network of stakeholders for the achievement of a common significant purpose*” (Purchase *et al.*, 2011b, p. 18). However, only when all stakeholders involved share a common interest in taking action towards a common purpose does the enterprise provide a reasonable scope for the analysis. For example, Selviaridis and Norrman (2014) highlight that for a close interaction between service provider and customer to take place, a common understanding about the provider's extent of responsibility for performance achievement is crucial. In more traditional buyer-supplier relationships the insight of each other's processes and the sharing of financial information is not always desired (Romano and Formentini, 2012). An in-depth discussion of how to create potentially efficient governance relations within the enterprise in the presence of stakeholders with heterogeneous goals is beyond the scope of this work. The reader is referred to Tirole (2001) for a theoretical baseline, and Kim *et al.* (2007) for a specific discussion concerning availability-based contracts.

Finding 2.1.2: PSS are socio-technical systems about which complete knowledge cannot be attained. Bounding these systems is a matter of determining the purpose of an investigation.

2.1.3 Not all outcomes of a system are desired

Although System Engineering provides a valuable framework especially in defence aerospace (Bartolomei *et al.*, 2012) for approaching socio-technical systems, it is the author's opinion that the field of accident investigation provides novel insight into socio-technical systems that can be of particular interest for the analysis of service systems. Both domains are concerned with outcomes: accident investigation focuses on undesired outcomes in the form of accidents or incidents, where service systems deal with doing something ‘right’ from the customer viewpoint (hence delivering value in-use) or dealing with the consequences of failing to do so. Crucially, within socio-technical systems failures and success exist for the same reasons, “*things go right and go wrong for the same reasons*” (Hollnagel, 2012, p. 22).

Two exceptional contributions in the field of accident investigation relate to large-scale multi-organisational delivery systems that produced highly undesired outcomes: *"The Challenger Launch Decision"* (Vaughan, 1997) deals with the explosion of the Challenger Space Shuttle shortly after lift-off in 1986. *"Friendly Fire"* (Snook, 2002) concerns the shooting down of two U.S. Army helicopters by two U.S. Air Force fighter jets in 1994. Both works were motivated by the lack of insight preceding investigations were able to provide.

The failure to send a shuttle into space and return it safely back to earth was attributed to a single malfunctioning component. The conditions for this component being 'allowed' to malfunction were blamed on flawed decision making processes and individual managers making the wrong decisions (Vaughan, 1997). Vaughan contradicts these findings and gives insights into why people have acted in the way they did and what the information available at the time before the launch *meant* to those involved. In this way she provides a much more elaborate analysis of the systemic conditions that enabled the outcome.

In the example of *"Friendly Fire"*, the failure to provide safe transportation in northern Iraq, the official investigation could not show a single culprit or *"smoking gun"* (Snook, 2002, p. 10). Snook's account of the events draws on detailed descriptions of the actions in their respective context. He concludes that to make sense of the events a wider view, across organisational boundaries, was required and that any analysis on a single level would miss the mechanism affecting the outcome.

A key lesson that can be learned from these analysis of socio-technical systems is that the way we look at phenomena not only influences, but determines what we are able to see and in the end determines what we are able to find (Dekker, 2011, 2006). This is also known as the *"What-You-Look-For-Is-What-You-Find"* principle (Hollnagel, 2012). Therefore, the model applied on the relationship between cost and the service system is a determinant for what we are able to find and ultimately do about it.

Finding 2.1.3: Socio-technical systems succeed and fail to deliver an intended outcome for the same reasons. Analysis, which considers the specific context and meaning, moving across pre-established boundaries can provide new insights for such socio-technical systems.

2.2 Conceptual integration of products and services

Before academia debated servitization and PSS, the academic literature has devoted a great deal of attention to the distinguishing features of such fundamental concepts as ‘products’ and ‘services’. Parry *et al.* (2011a) provide an overview of this debate, and conclude that products and services are rarely definitive and distinct. Hence, this section focuses on common characteristics of service and products for integrating them in a PSS model consistently. The product/service dichotomy has led the debate since the early 1980s – a period of high conceptual interest and enthusiasm in services and their distinguishing characteristics (Johnston, 1999). Spring and Araujo (2009) have criticized the use of such characteristics (generally referred as IHIP – intangibility; heterogeneity; inseparability; and perishability) as a basis for defining services, and objected that the interplay with products in “*bundled*” packages can be so subtle and difficult to capture that there is still not a coherent picture of how they are combined. Recently, Park *et al.* (2012) have presented an extensive review of the literature and observed that the integration of products and service occurs at two distinct positions in the value chain. In what they refer to as the “*marketing-oriented*” view the integration is close to the customer, and therefore realised mainly through customer service and sales functions. In such view product and service can be separated and offered independently, mainly because their integration is not considered at an earlier stage. By contrast, the “*engineering orientation*” (Park *et al.*, 2012) is concerned with the design of “*fully integrated*” solutions that provide functions the customer wants. The methodological support for New Product and Service Development Park *et al.* (2012) provide reflects that engineering design perspective. The same authors identify “*the role of technology*” as one dimension of product-service integration. The multitude of meanings of technology, as discussed by Mitcham (1994) does however show that there can be ambiguity around such notion. To this regard, Thenent *et al.* (2012) point out that the concept of *technology* might rather add confusion than clarification when searching for commonalities between products and service.

From the marketing perspective a substantially different view on product and service integration emerges. Within ‘service-dominant logic’ (SD logic) both goods and services are employed to deliver ‘service’, and while the role of goods is reframed as “*Mechanisms for Service Provision*” (Vargo and Lusch, 2004, p. 8) key

concepts of the service-dominant logic are *operand* and *operant* resources. Vargo and Lusch (2004, pp. 2–3) define *operand* resources as those “on which an operation or act is performed to produce an effect” whereas *operant* resources “are employed to act on operand resources”, hence “operant resources are resources that produce effects”.

Similar concepts have appeared much earlier in an apparently unrelated, product-centric field of research, namely in the abstract Model of Transformation Systems which was first published as a draft by Vladimir Hubka in 1967 (Eder, 2011).

Within the Model of Transformation Systems *operands* are being transformed from a state one into a state two by *operators* that could be for example humans or technical systems. It is the general application of knowledge, used as a synonym for ‘service’ by Vargo and Lusch (2008, p. 4), and the application of the operator’s knowledge within the transformation process in the Model of Transformation Systems, that is fundamental to SD logic and the Theory of Technical Systems. The above suggest that SD logic shares – without explicitly acknowledging it – fundamental concepts with the Model of Transformation Systems and hence, the Theory of Technical Systems. Additionally, both rely on the exchange of information between elements constituting the system. Vargo and Lusch even “argue that the primary flow is information; service is the provision of the information to (or use of the information for) a consumer who desires it, with or without an accompanying appliance” (2004, p. 9). The possibility for an “appliance” can be seen as a reflection of a flow of material and resources within the Model of Transformation Systems (Hubka and Eder, 1988).

Finding 2.2: Products and services can conceptually be integrated by the flow of information and material between transformation processes.

2.3 Availability as an advanced service

A particular type of advanced service is the provision of product-related availability under incentivising contractual mechanisms known as availability based contracts (Baines and Lightfoot, 2013). Although several definitions of availability can be found in the literature, a concise and effective one is given by Jazouli and Sandborn (2010, p. 1): “Availability is the probability that a system will be able to function when called upon to do so.” Similar or slightly different definitions are widely used to address both the general methodological problem of availability (e.g., Villemeur, 1992; Blanchard, 1992; Ntuen and Moore, 1986) and

more specific applications to contemporary performance-based procurement policies (Doerr *et al.*, 2005), especially regarding military aircraft (Farnell, 1984; Jacopino, 2007; Andresen and Williams, 2011). Besides terminological differences, there seems to be agreement that availability is a measure for the time a system performed as requested compared to the total time a system was deployed. With reference to military avionics, Schor *et al.* (1989) specifies that mission readiness is the availability of a particular function at the beginning of a mission. Hollick (2009) further refines the notion of avionics availability as a function of Non Fully Mission Capable Time (i.e., the aggregate of the elapsed time that an end-item is in an unserviceable state or in a partially mission capable state), based on the consideration that an end-item may be in an operable and committable state, but not for a particular mission because a specific mission critical component is in a failed state. In the view of Rijdsdijk (2013) availability is a quality indicator relating a required function of a product to its inherent ability to deliver that function.

A common feature of the literature in the field of reliability engineering is that availability tends to be related almost exclusively to the reliability features designed-into a technical system. In particular, prediction of the availability of a product instance, which on failure can be restored to operation by repairs or replacement, tends to be based on the assumption that the distributions of uncertain times to failure and times to repair are known or can be estimated (Ntuen and Moore, 1986; Sandborn, 2013). Even when it comes to advanced service, delivered by a PSS availability is commonly metricated according to product characteristics, see for example Baines and Lightfoot (2013, p. 132). Zio (2009) emphasizes that in an economy that shifts from valuing the product itself to valuing the performance of the product in providing a service to the customer, it becomes more appropriate to focus on “service availability”. Service availability, according to Zio (2009) is a performance outcome resulting from the interaction of technical as well as social (human, organisational) systems in interrelated processes. The concept of service availability poses a challenge to the traditional analytical formulation of availability, which is underpinned by assumptions about complete knowledge of product features, well-defined boundaries and fully known states, such as operating or repair conditions. In particular the role of maintenance in PSS is discussed in the following sub-section.

Finding 2.3: In the delivery of advanced services as well in other contexts, availability tends to be metricated referring exclusively to characteristics of the product.

2.4 Maintenance in PSS

In long term service agreements, such as availability contracts maintenance support plays a crucial role to ensure that performance guarantees can be fulfilled (BS EN IEC, 2009, p. 11).

2.4.1 Maintenance activities in availability provision

In the case of availability provision for a military aircraft, as shown in Figure 6, the service outcome is a technical system being in a fully mission capable state, that is no mission-critical items or sub-systems are in a failed state (Hollick, 2009). In civil aviation the same outcome is expected from the Maintenance Repair and Overhaul (MRO) sector (Ayeni *et al.*, 2011, p. 2109). In any case, while the aircraft is a necessary enabler for the user's ability to successfully perform missions, both user's and service provider's activities, resources and competencies are required for the aircraft to be functional when it is requested. The extent to which the service provider's maintenance activities can be considered successful in terms of contribution to the final achievement of rendering value 'in use' depends on how performance is defined and which metrics are put in place. In other words, the service-outcome "availability" depends on the performance of the maintenance organisation (Ignizio, 2010). While referring to a more traditional production environment, Kelly (2006, p. 42) describes the maintenance organisation as a sub-system of a company that contributes to the overall company function.

In case of a military aircraft, as shown in Figure 7 exemplifies the concept for a military aircraft. The PSS provider is concerned with answering "Yes" to the question "Aircraft ready?" asked when the customer "wants to fly" (utilisation is called for), all other enabling conditions being fulfilled. In this context, successful maintenance is turning a "no" into a "yes" to meet the customer demand.

In a PSS context, whether a maintenance intervention is successful is determined not only by the occurrence of a defect repair, or the replacement of a unit, but also by the extent to which it is aligned with the user demand. For example, the

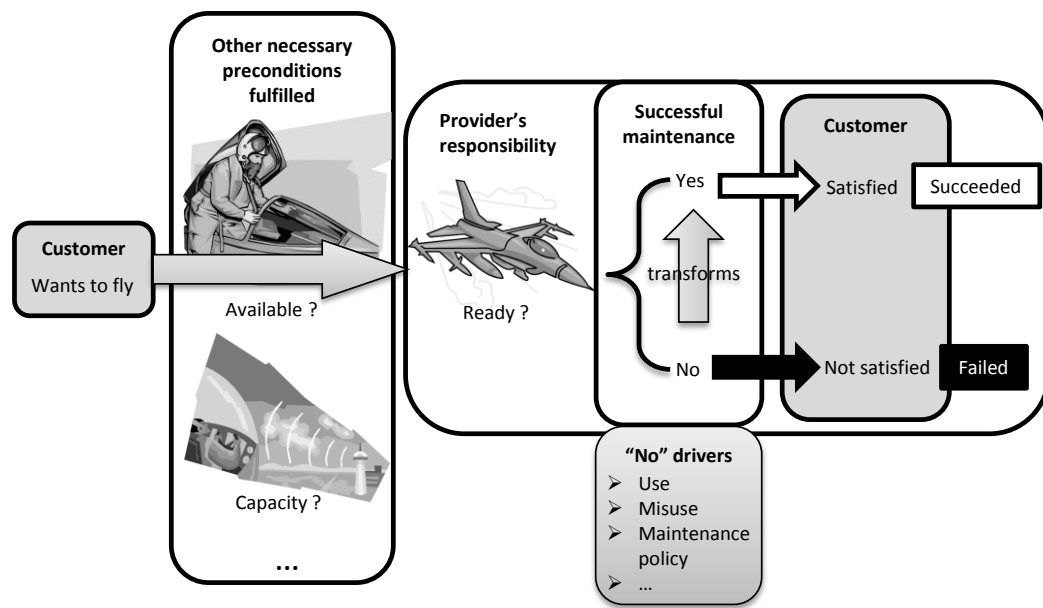


Figure 7 Successful maintenance in the core of providing flyable aircraft.

intervention must be timely: an aircraft may be ready to fly, but the user is not demanding it. Another example is an aircraft available for one particular type of mission, but due to a failed component not for another (Hollick, 2009). Also, long periods of ‘unavailability’ may generate misalignment with the customer demand, but in case availability is measured as an average over a time interval, the contractual performance may still be met (Hockley, 2011).

Product-related reliability and maintainability influence the scaling of the supply chain, aircraft unavailability is however controlled by managing the employed resources (Hollick, 2009, p. 247). As exemplified by Wilkinson *et al.* (2002) an established failure rate will not tell a planner how long a particular piece of equipment will continue functioning. Products employed by the final user, such as aircraft and ships, are composed of multiple sub-systems and components. To ensure availability of high value replacement parts and modules a suitable supply chain needs to be lined up (Aurich *et al.*, 2006; Andresen and Williams, 2011).

Although maintenance is seen as a critical enabler for delivery, representing maintenance in PSS is still problematic. Aurich *et al.* (2006) show interlinked product and service processes for the design of PSS in a linear chain. A network representation is adopted by Kim *et al.* (2011b) that does however not include maintenance. Most models of PSS delivering such advanced services as

availability model the mechanisms of failure of individual products, rather than the maintenance organization as a socio-technical system. For example, Löfstrand *et al.* (2012) recognise the importance of maintenance for delivering product availability. However, their use of Petri-nets is limited to the computation of the number of product-related failure occurrence. Similarly, Lanza and Ruhl (2009) model the provision of service under a machine support contract by focusing on stochastic time distributions of undertaking a maintenance task. Stochastic failure behaviours are also dominant in the model proposed by Komoto *et al.* (2011) for a PSS providing functional upgrading service of a computer-embedded system. Other works like Meier *et al.* (2010b) and Trappey *et al.* (2011) focus on the automation of communication and negotiation among organizations involved in the provision of technical systems' support contracts, e.g., by using multi-agent systems approach and IT solutions. A specific case in aviation maintenance can be found in Zhu *et al.* (2012).

Finding 2.4.1: Maintenance is a critical enabler to the successful delivery of availability. However, the operation of the maintenance organization is rarely modelled as part of the PSS; rather the focus is on an individual technical system and its designed properties.

2.4.2 Performance measurement in maintenance

According to Neely *et al.* (2005) performance is attained through the actions that a business undertakes. The level of performance achieved depends on the extent to which customer requirements are met (effectiveness), and the economical utilization of resources (efficiency) respectively. It is expressed in terms of quantified indicators that are distinguished between leading and lagging. The latter reflect results of events that have happened in the past (for example, machine failures and downtime due to maintenance that have already occurred), whereas leading indicators enable the proactive management of process performance (Smith and Mobley, 2007). Quantification of performance poses a challenge in itself, and even if appropriate indicators are selected, it is still important to understand *how* these measurements are taken, as for example subjective judgement can lead to inconsistent recordings (Sumerlin, 1971; Blackwell and Hausner, 1999). Nudurupati *et al.* (2011) provide a state-of-the-art overview on the subject. They highlight that performance measurement is

embryonic in the context of servitization and SD logic, and that more empirical research is required to explore these fields.

Most of the measures used to quantify maintenance performance are lagging indicators. This is demonstrated by a recent literature review on maintenance performance metrics between 1979 and 2009 (Simões *et al.*, 2011). The authors identify “cost”, “overall equipment effectiveness”, “availability”, “reliability”, and “downtime” as the most recurring metrics in the literature. Also, from an asset availability point of view *maintainability* and *reliability*, at times accompanied by *supportability* are widely considered as determinant (Jacopino, 2007; Sandberg and Strömberg, 1999; Crocker, 2010). If considered as designed-in features these characteristics can only be influenced through redesign (Andresen and Williams, 2011). However, unless the asset is deployed, and put into operation none of these metrics reflect any delivered performance in availability provision (Wasson, 2006). Being insensitive to changes in the support environment once established these metrics can be misleading (Blackwell and Hausner, 1999). Similarly, Hollick (2009) cautions about the use of performance metrics that are directly related to the end item, as a diversity of organisations and capabilities contribute to the level of performance that is achieved. Smith and Mobley (2007) stress that it is impossible to manage results in terms of achieved availability or reliability without managing the maintenance process. In this light the findings presented by Simões *et al.* (2011) surprise even more. Not only do maintenance organisations rely mainly on lagging indicators, “process performance”, “customer satisfaction”, “skills”, and “resource utilisation” are among the least employed metrics. In particular in a PSS context that requires customer focus and continuous adjustment to changing conditions it is these indicators that seem most appropriate. With particular reference to the ATTAC service enterprise Parry (2010) confirms that performance measurements are sometimes placed where convenient, not necessarily where valuable. With reference to performance-based contracts, Selviaridis and Norrman (2014) highlight the importance of attributing performance to the service provider’s input and effort. The lower the attributability of performance to service provider input, the lower the service provider’s willingness to linking its payment to performance achievement.

A selection of input parameters for maintenance performance indicators given by Raju *et al.* (2012) in Table 3 shows that maintenance performance is determined

Table 3 Examples of performance indices and how the attributes governing them enter their computation (based on Raju *et al.*, 2012).

Index	Attributes governing performance (descriptive input)	Computational input	Degree of insights about specific context provided
As good as new	Benchmark methods, workmanship, quality assurance, expertise; Insulation and grounding.	No of work records; No. of work records meeting new as standard; Percent residual life; System category.	Computational input only captures the results of the descriptive input. Context is given by system category.
Time	Procedures, enterprise resource planning, motivation, focus.	Desired inspection time; extra time;	As above, computational inputs capture the results. No specific context given.

relying mainly on numerical values of attributes with little or no context. Only the “System category” in the “As good as new index” provides information about the specific context. No insights are provided about operating conditions or other events that could explain why attributes take the numerical values they do.

Finding 2.4.2: Result-oriented and activity-oriented indicators determine performance in maintenance. Product performance is mainly determined by built-in reliability and maintainability metrics.

2.4.3 Conditions for successful maintenance

Kinnison (2004, p. 1) points out that maintenance relies on sciences, but it is also an art because problems that seem identical demand and receive varying approaches and actions on a regular basis. The following quote further illustrates such view on maintenance:

“For the most part, [the Concordes] are kept operational by the loving care and attention of engineers who deal almost exclusively with this aircraft.” (Reason, 2000, pp. 310–311)

Successful maintenance seems to be a suitable example for the delivery of “value in-use” to the customer (whether internal or external to an organisation) of the maintenance organisation. As suggested by Kelly (2006) with reference to the manufacturing industry, in a Business-centred view of maintenance the centralised maintenance functions can be seen as providing a service to the

manufacturing units. As such, these maintenance functions are concerned with efficiency of resource usage, acting like internal contractors.

Successful maintenance is determined by its effectiveness in providing an available aircraft when required, and its efficiency by the use of resources. The latter is affected by the production of undesired outcomes, such as undetected faults or accidents and scrap that use up resources without contributing to the final delivery. Hence, successful maintenance also means safe maintenance, with the literature on safety in aviation providing valuable insights. Reiman (2010) identifies twelve factors, arranged into organisational, social, and individual elements that affect maintenance in a positive way.

Task related knowledge is one of the elements in the latter category, as maintenance always needs to rely on the competency and skill of the personnel, for example an understanding of how a technical system works and not only knowledge about individual components (Goettsche, 2005). Their training, motivation, experience, and working environment form a necessary precondition alongside their attitude, conduct and personality (Simões *et al.*, 2011).

Positive social factors include clear communication, and that embraces communication between different departments in an organisation (Veldman *et al.*, 2011). In the context of PSS this can be translated into the need for a close linkage between all parties involved, including the customer and user. Exchange between technicians and operators is crucial to acquire and enhance understanding of the technical system and to know how it is supposed to be used (Kinnison, 2004; Leney and Macdonald, 2010; Reiman, 2010; Aubin, 2004). Additionally, the importance of data and information from equipment failures, condition monitoring and reliability programs, and service reports is underlined (Kinnison, 2004). In this research it has become evident that practices of on-aircraft maintenance, were not favouring the supplier's activities, leading to additional work. Further more, the lack of useful insight from operators or maintenance personnel on other levels has been stated as being hampering for sub-system repair, and for failure analysis. Suwondo (2007) confirms the latter looking at pilot and maintenance reports.

One explanation for field reports providing little insights can be the time pressure maintenance personnel are frequently facing when assessing a situation (Knezevic,

1999). This mandates high maintainability, easing the identification of a failure, and access to the affected components (Fielding, 1999). Built-in test equipment or more sophisticated condition monitoring can significantly reduce the time needed to isolate and rectify a failure (Dabell *et al.*, 2009; Tall, 1971). If such equipment is not reliable it can however have counter-productive effects (Beale and Hess, 2000). In the absence of built-in test provisions adequate test equipment needs to be at hand to avoid false findings (Curry, 1989). The activities following the removal of a functioning unit use in principle the same resources as does a defective unit (Knezevic, 1999). To ensure that actually no fault is found testing can require even more effort than usual (Curry, 1989). An issue that has been raised in this research is that a sub-system that gets send back to the repair provider may only be released back to service when meeting production level test standards requiring additional rework.

One factor for a successful condition monitoring system is the involvement of experienced engineers being knowledgeable about operating conditions (Beale and Hess, 2000). Followell (1995) gives examples of environments that are significant for the reliability of external stores. The environment does not only affect the product-related performance, it is also of interest for the ability of the personnel to perform their tasks satisfactorily. Even more so when conditions can change, such as during war operations, at an airport gate, or apron (Knezevic, 1999).

It is the maintenance organisation that has to provide all required resources at the right time (Aubin, 2004) in a favourable environment. To do so a maintenance program suitable for the particular needs and conditions needs to be established and to be translated into clear and concise manuals and task descriptions (Ghobbar, 2010; Aubin, 2004). Blackwell and Hausner (1999) show how practices after the identification of a discrepancy impact on the use of resources. Maintenance technicians would remove a defective unit on one aircraft type and send it back to the repair shop. On another aircraft the unit would be aligned by the technician on board the aircraft, not causing a repair. Similarly, availability is affected by practices that allow findings to be deferred, as in commercial aviation or required immediate rectification, as in military aviation (Hockley, 2011).

Finding 2.4.3: Successful maintenance depends on individual, social and organisation factors. These factors need to be supported by appropriate documentation and technical systems in a favourable environment. Effective communication between all elements (including the technical system) is essential.

3 Cost modelling

Cost modelling is an ‘a priori’ analysis with the purpose of creating a forecast of future expenditures. As such, cost modelling is not necessarily concerned with *managing* future expenditure or cost. In a similar manner, cost tends to be addressed as something to fear and forecast (similar to an adverse meteorological event) and not something to understand and manage. This is particularly evident, for example, in the case of the F-35 Joint Strike Fighter where frequent unit price increases and program delays continue to cause controversy over the aircraft acquisition process (Fulghum *et al.*, 2011; Coghlan, 2012). Cost estimators and modellers have long been concerned with predicting how much something costs using aggregate data and drawing on past experience of cost outturns, rarely asking why it will cost that much (Dean, 1993). This approach may give the impression that progress in understanding and controlling cost is being made despite the fact that the problem is only partially understood. The drawback in cost prediction for projects is typically a “fire fighting” approach to project problem resolution, resulting in a chance that, as and when the desired results are delivered, the asset is provided late and at a higher cost than planned (Burge, 2010). An overview of the current academic standpoints and research agenda in cost engineering highlights that research is needed to support manufacturers that have servitized in costing the provision of advanced services such as availability via PSS (Xu *et al.*, 2012). However, costing for PSS is still in its infancy. In particular, a critical reading of early overviews and frameworks suggests that concepts such as ‘servitization’ and ‘PSS’, despite their innovative content, do not seem to have destabilised the prevailing practices in cost estimation. Datta and Roy (2010) review the literature and outline a framework, but eventually suggest combinations of existing cost estimation techniques. Huang *et al.* (2012) identify the challenges of adapting these techniques for the purpose of service cost estimation, but without addressing an autonomous methodology.

In the reminder of this section, the relevant literature on cost estimation is reviewed based on three fundamental aspects: the purpose (why?); the approach used (how?) for creating a cost estimate; and the object of analysis (what?).

3.1 *Purpose of cost estimation – why*

Commonly, the purpose of cost estimation is stated referring to its intended application, e.g., to support affordability studies, source selection studies, design trade-offs etc. (Asiedu and Gu, 1998). In the light of recent critiques (Keller *et al.*, 2014), the purpose should also be investigated in terms of whether insight is needed to provide a number that will get a ‘one-off’ approval, such as for budgeting purposes, or for controlling cost on a continuous basis.

The latter purpose underpins a more strategic management of costs. Insight is required to create or sustain a competitive advantage within a specific industrial setting by looking both ‘inward’ and ‘outward’ to an organisation’s suppliers, customers and competitors. The advantage sought tends to relate to efficient resource usage, increased value delivered to the customer and strategic positioning in the marketplace through exploitation of the activities contributing to customer value realisation (Cinquini and Tenucci, 2010). The scope of the analysis is framed in terms of activities undertaken both within the individual firm’s value chain and with suppliers upstream and customers downstream (Hansen and Mowen, 2003).

The other purpose, the generation of a one-time cost estimate independent of specific organisational and industrial settings, is should-cost estimating. Should-cost estimation applies when the relationship sought with other actors is of an arm’s length type as opposed to a strategic alliance (Ellram, 1996). A typical example is an organisation assessing the fairness of the price a supplier charges by independently calculating a product’s should-cost. Another example is the comparison of competing product designs, where a cost estimate has to be generated in the absence of a profound understanding of the product, the methods of manufacture/processes and relationships between processes (Roy, 2003). In this case, knowing cost in absolute terms may not be the main aim, rather, relative accuracy is sought (Sandborn, 2013).

Typically, most of the attention towards a product-accompanying service cost estimation (for example the support logistics system) is concentrated at the very early stage of designing a product and its support system (Blanchard, 1992). This is particularly evident from the common practice of mapping cost estimation techniques against the context of product development, from design, through manufacturing to after-sale support (Newnes *et al.*, 2008).

In the following *bidding* process the customer issues a request for proposal (RFP), based on an acceptable price is that he is willing and able to pay, to competing providers. This includes defining the most suitable way of flowing performance criteria associated to the final “PSS Delivery” down into the supply chain (Kim *et al.*, 2007). An RFP might already be based on a fixed budget. In that case it is up to the competing providers to meet the specifications and promise a lower price, or better performance than the competitors. In any case, the potential provider needs to understand whether he can offer the service, win the contract and still make a profit (Bowman and Schmee, 2001). At his stage the potential provider will estimate the cost of offering the requested service, including the need for resources from external suppliers through-out the contract duration. Considering potential penalties, or even more so in the absence of these, the provider may be tempted to undertake trade-off studies between meeting the required performance criteria and minimising his expenditure and penalty (Hockley, 2011). As pointed out by Nicolini *et al.* (2000) the above described may not be what is happening in practice. Rather, the bid submitted by the potential supplier is based on what is perceived as an acceptable price in the market place. In competitive tendering an atmosphere of mistrust between the buyer and supplier, combined with pressure to reduce prices can lead to lowering specifications, compromising quality and jeopardizing profit. Assidmi *et al.* (2012, p. 1) highlight that cost estimates being produced under such pressures may be manipulated or ignored.

The deliverable outcome is so far merely considered in specifications, requirements and possibly the definition of Key Performance Indicators (KPIs). Perrigo and Easterday (1974) highlight that the customer should be concerned with *how* these are planned to be delivered by the provider, to ensure that delivery is indeed satisfactory from his viewpoint.

Based on a critical review of the literature Settanni *et al.* (2014, p. 10) summarise that in PSS, should-cost estimation independently undertaken by the customer or supplier tends to be the prevailing approach. The authors highlight that most cost estimating approaches have been developed within a product and support business model which incentivises a “*throw-it-over-the-wall*” to the customer approach, rather than the attainment of continuous value in-use through the contribution of resources from different actors. By applying cost estimating techniques developed with the purpose of supporting ‘one-off’ decisions, and arms-length strategic relationships, the implicit assumption is that there is a clear-cut distinction between responsibilities, and hence the cost elements of interest for the customer and the provider (Chen and Keys, 2009). This is in sharp contrast with the idea of delivery of value in use through a PSS discussed previously in section 2.

Finding 3.1: One-off should-cost estimation is suitable for customer supplier relationships at “arm’s length”. Should-cost estimation is the prevailing approach used in PSS. By contrast, strategic management of costs focuses on the activities within the enterprise, across organisations.

3.2 Cost modelling methods – how

This section gives an overview of cost modelling methods. The specific aim is to ascertain whether and to which extent the characteristics of that PSS are reflected in different methods. A distinction is made between techniques that can provide analytical explanation in order to act on the result and those whose rational is based upon the purpose to produce a single or multiple figures forecast. Table 4 summarises some distinctive methodological aspects of cost models.

The distinction between associative and causative models reflects the classification proposed by Curran *et al.* (2004). Associative models are based on establishing a relationship, often having a statistical nature, between historical expenditure data and selected quantifiable characteristics of the unit of investigation. They can be employed for communication, as in negotiations with a supplier, do however not support cost reduction decisions with analytical insights.

Unlike associative models, causative models emphasize the developing of a causal understanding prior to the estimate of cost (van der Merwe, 2007b). These models

Table 4 Classification of cost modelling techniques.

Modelling rational Concept of cost	Causative models Provide analytical explanatory facilities	Associative models Generate forecast from aggregate past spending outturns
Spending-models Handle one item at a time; Monetary measures directly and immediately relate to it (cash flows and expenditure).	I Engineering/Bottom-up (Suwondo, 2007) Feature-based modelling (Evans <i>et al.</i> , 2006) Reliability-based modelling (Waghmode and Sahasrabudhe, 2011)	II Analogy/ Case-based reasoning (Banga and Takai, 2011) Parametric (Hart <i>et al.</i> , 2012) Expert judgement (Emblemsvåg and Tonning, 2003) Artificial Intelligence (Gitzel and Herbort, 2008)
Resource consumption models Handle multiple activities and deliverables simultaneously; Money is a meta-language providing a value representation of the flow of goods and services	III Activity based costing (Emblemsvåg, 2003) Material and Energy Flow Costing (Möller, 2010)	IV N/A

are often criticised for being inherently incapable of allowing for costs that cannot be identified at the time of making a forecast (Pugh *et al.*, 2010).

3.2.1 Methods based on analytical relationships

Traditionally, causative models are collectively identified as the “*engineering*” approach to cost estimating. According to Stewart (1982), such an approach reflects the need to assure maximum productivity in project completion by efficiently and effectively managing the jobs to be done, and allocating the necessary resources. A common way of going about engineering cost estimation is by breaking down a product cost into key constituents via engineering analysis and calculation (see for example Curran *et al.*, 2004).

Estimating by engineering procedures involves an examination of separate component tasks which are then structured according to strictly hierarchical relationships as a “Work Breakdown Structure” (WBS) (Stewart, 1982). The engineering estimator begins with a complete design and specifies each production or construction task, equipment and tool needed, and material requirement. Costs are assigned to each element at the lowest level of detail. These are then combined into a total for the product system (Fabrycky and Blanchard, 1991). Analytical methods allow evaluation of the cost of a product from a

decomposition of the work required into elementary tasks, operations or activities with known (or easily calculated) cost. Some analytical methods for cost estimation advocate integrating process information with product cost information. For example, Curran *et al.* (2007) estimate the cost of a fuselage panel design by that includes the management of product, process and resource (PPR) data through integrated digital manufacturing. Ben-Arieh and Qian (2003) estimate the cost of designing rotational parts in a specialised medium size design and development shop. In general this method is prone to rely on product-related features that define the cash outflows directly associated with the time span a product is with the user, typically referred to as operation and support. For example Suwondo (2007) employs this approach to evaluate alternative proposals for aircraft modifications, maintenance interval escalation and aircraft selection.

The engineering approach to cost estimation is sometimes addressed as “bottom-up”, as it is based on the assumption that an overall estimate of effort for a whole project can be broken down into the effort required for individual component tasks, for example the WBS for a product/system. Component tasks are identified and sized and the individual estimates are aggregated to and the individual estimates are aggregated to produce an overall estimate. In principle it is a simple method: determine the time needed to perform an activity and the hourly rates for the man and machine, then multiple times and rates to get the costs (Asiedu and Gu, 1998). It appears that the bottom-up method is strong in detail and causation but needs a detailed knowledge of the product and processes (Curran *et al.*, 2004). A particular case in engineering cost estimation is the use of CAD/CAM models that are integrated with cost information for cost estimation early in the design process via feature-based modelling (Evans *et al.*, 2006). Examples for such approach include Castagne *et al.* (2008) for the design of aircraft fuselage panels and Tammineni *et al.* (2009) who provide a case study for the design of a turbine disc. As feature-based methods focus on estimating the cost of a product unit during product design operating costs that incur during the in-service stage are usually obtained by a ‘factor’ that relates to product characteristics. Hence, feature-based methods do not provide useful insights once the equipment is fielded. However, data derived from the usage and support could be fed-back to improve this method for product design evolution. Early *et al.* (2012) propose to

apply a feature-based approach to services such as the provision of a search and rescue surveillance mission.

Another prominent example for methods that based on analytical relationships is the traditional reliability engineering approach to Life Cycle Cost modelling. The reliability engineering approach is concerned with improving the trade-off between acquisition and support cost by improving its reliability and maintainability features (Ntuen and Moore, 1986; Dhillon, 2010; Blanchard, 1992). An example is reducing support costs to product inherent reliability and maintainability (Fabrycky and Blanchard, 1991). A precondition for this method is that the cost of each element is known, as for example the cost for one repair that can then multiplied with the number of repairs of the in-service time (Schor *et al.*, 1989; Waghmode and Sahasrabudhe, 2011). With respect to PSS, the reliance on product features could conveniently side line the need to consider the operations of the user and the supply chain explicitly. Most PSS cost models are based on reliability features designed into a product, which are determined in laboratory conditions. This is evident in such advanced service cost models as those proposed by Jazouli and Sandborn (2011) and Huang *et al.* (2012). The main limitation of such an approach to service cost modelling is that it cannot be used continuously through an equipment life to support cost consciousness, that is, an understanding of a product's cost behaviour (Lindholm and Suomala, 2007). With the exception of Settanni *et al.* (2014) such a view has not been endorsed with regards to PSS.

In PSS not only the number of activities matter, but most importantly how they interact and how they depend on each other. A simplified breakdown structure can therefore not represent the relevant characteristics of PSS.

Finding 3.2.1: Analytical methods require a detailed breakdown of the investigated cost object and known cost rates for each item. The total cost is determined by the summation of the cost of all items.

3.2.2 Associative, spending-based methods

The most common approaches shown in quadrant II Table 4, parametric cost estimation, analogy modelling and expert judgement are discussed in the following.

Parametric cost estimation seeks to evaluate the costs of a product from attributes characterizing the product (usually those used by the designers) without describing it completely (Ben-Arieh and Qian, 2003; Evans *et al.*, 2006). Parametric cost estimation is carried out by deriving aggregate relationships between cost and these physical / performance characteristics from related historical data, generally following the principles of statistical inference (Dodson, 1979). Based on the assumption that any dependant cost or performance variable has the tendency to be related statistically to a product's attributes, a correlation between cost as the dependant variable and the cost driving parameters as independent variables establishes the statistical accuracy of the relationship. (Pugh *et al.*, 2010; International Society of Parametric Analysts, 2008; Curran *et al.*, 2004; Stewart, 1982). This method typically seeks the criteria of speed of results but without good explanation facilities, because parametric models do not intrinsically require that causal cost drivers are used as independent variables. Hence, the relationship among the identified variables is often merely one of statistical correlation (Dodson, 1979). As a result it can be extremely difficult to draw sensible conclusions from parametric models. It is therefore not considered as a suitable method to support informed decision making (Curran *et al.*, 2004).

Analogy cost modelling is associated with comparative costing according to the similarity and differentiation of like products with known cost. A precedent at product level (or a similar, completed, project) is identified and its recorded costs are used as a basis. The cost of the case chosen is then adjusted relative to differences between it and the target product. The effectiveness of this method depends heavily upon the ability to identify correctly the differences between the two cases (Curran *et al.*, 2004). The shortage of relevant data at a comparatively high level of detail often prompts a further disaggregation of the system under study in order to draw upon a wider base of analogous subsystems and components (Dodson, 1979). Similarly, case-based reasoning uses old cases/experiences to understand and solve new problems. It consists of creating a database or library of previous cases, retrieve situations similar to the problem at hand and generate a solution based on adjusting the cost of the retrieved cases to the new case (Evans *et al.*, 2006). The difference between case-based reasoning and analogy is that the latter does not rely on detailed design and manufacturing information (Banga and Takai, 2011). In the case of PSS it is very difficult to

compare different cases to identify commonalities and differences. Unless a method for visualising the activities and their resource consumption is used there is a risk that the comparison is restricted to the product level. Once the specific context is lost the information employed is reduced to data limiting the insights provided.

Expert judgement methods are based on past experience of the estimator or experts from the domain in which the estimate is being made (Ben-Arieh and Qian, 2003). Heuristics in knowledge-based models integrate and link rules of thumbs and lessons learned in a formalised way (Valerdi, 2011). Depending on how specific the heuristics are, they can be difficult to apply to different contexts. In a long-term delivery lessons learned do however offer a valuable chance to improve models and forecasts. In any case, as stressed for the other approaches as well, carefully considering the context is a necessity. This includes avoiding hind-sight bias (Dekker, 2006).

The methods introduced in this section rely heavily on past data and information. Lacking context the applicability to the situation at hand needs to be ensured carefully. For decision making in PSS lessons learned and heuristics can prove valuable, while parametric techniques cannot offer much support.

Finding 3.2.2: Associative, spending-based methods require significant knowledge about past comparable cost objects. The specific context can easily be lost when using forecast-based approaches.

3.3 Cost object – what

Cost objects are the elements, typically products or services that can be identified within an organization, whose monetary value is determined through the process of costing, and so to speak represent the focal point of cost modelling (Hansen and Mowen, 2003). This section reviews common cost objects in PSS suggested by the literature.

As discussed in section 2 a PSS delivering advanced services is a socio-technical system which takes the form of a network of interdependent activities performed across multiple organizations within the boundaries of the enterprise, for the achievement of the common purpose. In availability provisions this purpose is for

example to continuously ensure that the means of production acquired by the customer are in an operable and committable state when needed.

Settanni *et al.* (2014) observe that most of the literature on cost modelling for PSS identifies the cost of providing a service via a PSS with the cost of the in-service stage of a durable product. The major difference is that, in the former case the cost object is, in principle, the delivery system itself, as well as its multiple deliveries considered simultaneously. In the latter case the cost object is the period of time over which a number of sustainment events directly attributable to a specific product unit occur (see for example Jazouli and Sandborn, 2011; Huang *et al.*, 2012).

Since section 2.4 Maintenance in PSS identified the maintenance organization as a relevant part of a PSS delivering an advanced service such as availability, this section examines the cost objects that are commonly used for determining the cost of maintenance and PSS. In the literature about maintenance cost is the most occurring performance metric (Simões *et al.*, 2011). However, to understand what such cost refers to (that is, what the cost object is) one should consider whether the focus of the analysis is:

- The organisational system delivering maintenance services; or
- The individual technical system sustained.

In the first case, the purpose of assessing maintenance costs is to provide a practical mechanism for planning and controlling the overall maintenance effort, and the efficiency of resources (Kelly, 2006; Bruggeman and van Dierdonck, 1985). The maintenance organisation is modelled as a system that contributes to the achievement of the results delivered by a higher organisational system by providing its services to it. Hence, this approach to maintenance cost modelling would fall in quadrant IV in Table 4. Examples concerning maintenance in a civil aviation include (Mirghani, 1996). Nevertheless, even if the use of such an approach is claimed, the determination of the cost of providing a support service may reduce to a service breakdown structure – see for example Kayrbekova *et al.* (2011). Most maintenance cost modelling approaches have the supported technical system, not the organisation delivering and supporting it, as the point of focus (Figure 8).

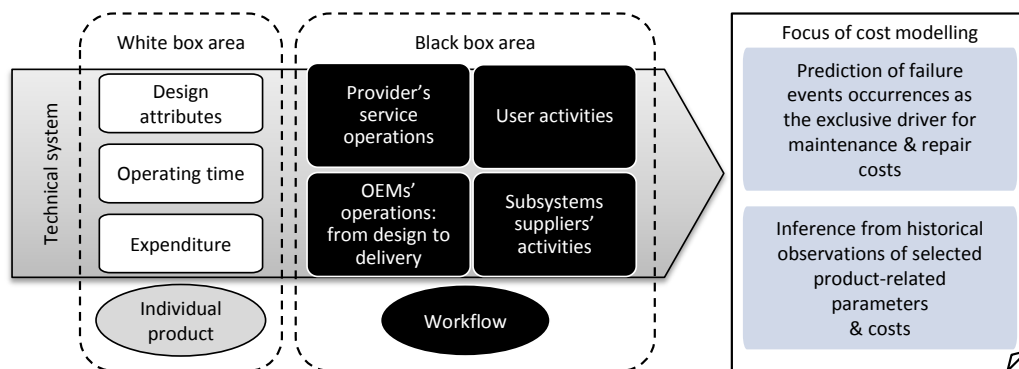


Figure 8 A technical system as the focus of cost modelling.

The literature is rich of approaches based on the application of reliability-engineering principles for estimating the cost of the in-service stage of a product – for an overview see Dhillon (2010). A distinguishing feature of these approaches is that they rely on a product unit's inherent reliability and maintainability to quantify upfront, and often one-off, the level of spending through the technical system projected life. This is particularly common when assessing defence programs at the *concept stage* (RTO (Research and Technology Organisation), 2007), and more in general to develop trade-off between alternative product designs based on their anticipated reliability (Schor *et al.*, 1989). As a consequence, studies tend to be carried out at design stage with very little knowledge of maintenance or operation associated cost drivers and processes (Datta and Roy, 2010, p. 147). Some of these approaches fall in quadrant I in Table 4. Similarly to the engineering approach for the estimation of the cost of manufacturing a unit of product, the reliability engineering approach breaks down a generic maintenance (repair) intervention into its constituent elements (e.g. direct material and labour), the unit cost of which is a given just as for each component in a WBS. However, whilst the number of components in a product breakdown is a given, the number of repair occurrences over a period of time (the product in-service phase) is modelled as a stochastic process (see for example Waghmode and Sahasrabudhe, 2011), or through a simulation (Jazouli and Sandborn, 2011) to determine the number of repairs/replacement that a product unit requires.

Other approaches, instead, fall in quadrant II as they consider directly the cost of servicing a technical system as a variable that has the propensity to be related statistically to some of the technical system's attributes (for example, Curry, 1993

and Huang *et al.*, 2011 for PSS). Example of the parameters used for modelling the cost of maintenance, i.e. servicing durable products is given in Table 5. Although not exhaustive, this list provides a good impression of the commonalities and differences between the inputs required for cost models of different purposes.

One difference between the two modelling approaches can be observed in how overheads are considered. While Roskam (1990) assigns overheads depending on the product and type of organisation with a fixed rate, Emblemssvåg (2003) uses actual expenditure designated as overheads to compute their contribution to a specific delivery.

Fundamental to the utilisation of the parameters in planning and control approaches is that they are contextualised due to a link to a specific activity. Context, namely the activities and their relationships are essential knowledge to

Table 5 Typical parameters required for modelling the cost of servicing durable products.

Purpose	Parameter	Reference examples
Occurrences of servicing event	Stochastic failure occurrence (Reliability)	Newnes <i>et al.</i> , 2011; Scanff <i>et al.</i> , 2007; Kim <i>et al.</i> , 2007; Nowicki <i>et al.</i> , 2008; Feldman <i>et al.</i> , 2009
	Labour rate	Roskam, 1990; Suwondo, 2007, p. 98
	Time to repair	Scanff <i>et al.</i> , 2007; Suwondo, 2007, p. 98; Feldman <i>et al.</i> , 2009
	Availability of spares	Huang <i>et al.</i> , 2011; Kim <i>et al.</i> , 2007; Nowicki <i>et al.</i> , 2008
	Annual utilisation	Roskam, 1990; Suwondo, 2007, p. 98; Scanff <i>et al.</i> , 2007
	Cost of a repair	Scanff <i>et al.</i> , 2007; Huang <i>et al.</i> , 2011; Feldman <i>et al.</i> , 2009
	Overhead rate	Roskam, 1990
	Duration of service delivery / product in use	Huang <i>et al.</i> , 2011; Greer, 1966
Both	Prices of consumables	Roskam, 1990; Emblemssvåg, 2003
	Material costs	Roskam, 1990; Suwondo, 2007, p. 98; Huang <i>et al.</i> , 2011; Nowicki <i>et al.</i> , 2008; Feldman <i>et al.</i> , 2009; Kelly, 2006; Kimita <i>et al.</i> , 2009
Planning & control	Labour costs	Kelly, 2006; Kimita <i>et al.</i> , 2009
	Use pattern	Emblemssvåg, 2003
	Activities	Kelly, 2006; Kimita <i>et al.</i> , 2009; Emblemssvåg, 2003
	Overhead cost	Emblemssvåg, 2003
	Duration of activities	Kimita <i>et al.</i> , 2009; Emblemssvåg, 2003

build up the model. They are specific for a particular context. For example the occurrence of failures as a result of the usage pattern and not only as a stochastic event resulting from aggregated time in use. There are however differences why and how such context is constructed, for example service design (Kimita *et al.*, 2009) or the analysis of an existing production system (Emblemsvåg, 2003). In models that determine the occurrence of servicing events the specific context has no influence on the parameters that need to be known. While the actual numbers may change, the computational structure does not.

Settanni *et al.* (2014) conclude that current approaches to estimate the cost of a PSS do not present any major discontinuity compared to the methodologies described above, which were developed in the same business context that availability or performance-based contracts are meant to overcome. As a result, most of the approaches to PSS costing tend to focus on a stand-alone asset when modelling the levels of performance a PSS provider is committed to deliver, for example under availability-based contracts. A notable exception is the approach suggested by Löfstrand *et al.* (2012) who propose a framework for estimating the cost of a “functional product” delivered by a PSS. The petri-net base simulation takes into account product characteristics as well as the support system in terms of maintenance strategy, procedures and resources, however without making explicit reference to how create such model from the specific context.

Finding 3.3: Approaches to maintenance and PSS cost modelling focus on the technical system supported, not the organisation delivering and supporting it. Context matters when using cost estimation for planning and control current approach. Commonly costs are determined by the number of repair interventions over a period of time neglecting the specific context of the repairs.

3.4 What is your cost model?

Here, ‘What is your cost model?’ is a re-interpretation of the question “*What is your accident model?*” asked by Dekker (2006, p. 81) to demonstrate the impact of our preferred view on what we are able to see. The subsections below summarise how different approaches to cost modelling can be translated into taking action, for example for cost reduction initiatives.

3.4.1 Cost is an intrinsic property of products

A common view on cost is to assume that cost is a dependent variable that has the tendency to be related statistically to the technical attributes used by the designers to characterise a product or service instance, or other features of a project. This model's use is typically focussed on speed of results, and allows changes in product's features through redesign to translate directly and immediately into changes in its unit cost. For example, Valerdi *et al.* (2005) adopt this model to calculate the yearly cost of an Unmanned Aerial Vehicle as a function of its payload weight and endurance.

Being based on a direct relationship between design features and cost (per unit, per year etc.), this cost model also promotes an idealised approach to product design which overlooks the challenge of cost allocation within the existing business environment (Barton *et al.*, 2001). Predefined and known cost figures for the system or component under investigation are expected to be retrieved rather than computed.

This cost model implicitly reflects an assumption which is commonly made in the literature: a significant portion of a product's cost is locked-in at its design (commonly quoted statistics are typically beyond 80%, see for example Newnes *et al.*, 2008). This assumption suggests, even in the absence of empirical evidence, that focus should be on product development, whilst diverting attention away from actions that can be taken in manufacturing or other downstream activities including use (Cooper and Slagmulder, 2004; Labro, 2006). Placing the responsibility for the costs incurred while the product is deployed exclusively on the designer creates the expectation that cost can be treated as an independent variable, just like any other engineering unit in the design process (see for example, Nicolai and Carichner, 2010). Hence, cost reduction measures are targeted at a product's features during its design.

3.4.2 Cost is a necessary evil due to cost drivers

Another view on cost rests on an understanding of "cost drivers" as something to drive out and get rid of or minimise. The expression "cost driver" is recurring in both literature and practice, but often misinterpreted. As Stump (1989) points out, cost drivers are often improperly used as synonyms for the cost categories in

which costs are classified; the most expensive (high value) item in a product; or the quantifiable product features discussed in the previous section –like weight, etc. – which can be statistically related to the unit cost of a product. For example, Erkoyuncu *et al.* (2011) identify failure rate, turnaround time, repair cost, LRU (Line Replaceable Unit) cost, and labour availability as “...*typical cost drivers that arise at the bidding stage of a contract for availability*”. Underpinning this view on cost is that cost drivers are decision elements that have instantaneous cash flow consequences. These decision elements are usually considered in isolation. Cooper calls these models “*spending models*” (Cooper, 1990). Maintenance, for example, is frequently dismissed as a necessary evil. In such a view maintenance efforts are unwelcome activities that drive costs therefore they should be avoided. The positive contribution of maintenance to the final delivery of an outcome, for example sustaining production in a manufacturing plant, is simply neglected (Kelly, 2006; Sherwin, 2000). For example, Browning and Heath (2009) demonstrate, with a case study of the F-22 production line, that cutting cost can remove the necessary conditions for successful delivery of desired outcome in the absence of an understanding how the system works.

3.4.3 Cost is an emergent property of a system

Finally, cost can be viewed as determined primarily by the dynamic behaviour of the system delivering products (or services) (Storck, 2010). In this case cost is an “emergent property”, and effective cost analysis must rely upon a consistent and transparent representation of the context within which products and services are designed and delivered (Field *et al.*, 2007).

In this case the knowledge required for the costing operation is more than just data and information (e.g. regarding a product’s cost and technical characteristics), rather, focus is on what the information represents, how to handle it and most importantly what action to take (Naylor *et al.*, 2001).

Models of virtual cost flows based on means (enabling conditions) and ends (desired outcomes) relationships within a system of interrelated operations have been developed, for example, in the field of material and energy flow costing (Möller, 2010). Another example is the application of Functional Analysis, which bases cost analysis on the functions or services provided through the activities

performed within an enterprise and how they are achieved (Yoshikawa *et al.*, 1994).

In this view, “cost drivers” are causal events which determine “why” work takes place and how much effort must be expended to carry out the work (Emblemsvåg, 2003). They measure the frequency and intensity of the demands placed on activities performed within an organisation, hence sometimes they express the output of an activity (Raffish and Turney, 1991). This view of cost drivers allows initiatives for cost reduction to be centred on improved efficiency, which measures the use of resources in activities performed in order to deliver an outcome (Neely *et al.*, 2005).

3.4.4 Comparison of perspectives

Table 6 provides an example of how the perspective taken towards costing may shape the understanding and action of an organisation, taking the example of the Watchkeeper UAS (Unmanned Air System) program (Hoyle, 2013b). Depending on the perspective of the individual, what is being delivered by the program ranges from a quantity of unmanned aircraft to tactical intelligence. In the latter case the Watchkeeper UAS may only be one option to deliver the outcome. Therefore, the costs incurred would not be attributed to individual assets, but rather to the activities required to deliver intelligence. The achievement of certification, more precisely the time needed to get there, is an example for a program cost driver. Consequently, reducing the time to certification leads to cost reductions.

Table 6 Different views on cost applied to the Watchkeeper (Hoyle, 2013b) example.

	Cost is an intrinsic product property	Cost results from cost drivers	Cost is an emergent property
Delivery	A number of UASs.	A certified UAS.	Tactical intelligence.
Origin of costs	Wing span or weight of the individual UAS.	Extended time for certification.	Activities necessary before, during and after deployment.
Possible means for reduction	Reduce UAS size.	Expedite certification.	Manage activities.

Finding 3.4: The perspective taken on a phenomenon determines the rationale for making decisions. Based on the perspective taken the meaning something has changes and hence the options for taking action change too.

4 Summary & identification of gaps

This section summarises the findings from the literature on PSS and cost modelling. Schematics are used to illustrate how mismatches between findings

Table 7 Summary of findings from the literature.

No.	Finding
2.1.1	PSS are service systems that achieve their outcome through resources being employed in activities. Emergent properties of systems can only be observed when investigating the whole system, and not the constituting elements in isolation.
2.1.2	PSS are socio-technical systems where complete knowledge cannot be attained. Bounding these systems is a matter of determining the purpose of an investigation.
2.1.3	Socio-technical systems succeed and fail to deliver an intended outcome for the same reasons. Analysis, which considers the specific context and meaning, moving across pre-established boundaries can provide new insights for such socio-technical systems.
2.2	Products and services can conceptually be integrated by the flow of information and material between transformational processes.
2.3	Availability tends to be metricated referring to characteristics of the product.
2.4.1	Maintenance is a critical enabler to the successful delivery of availability.
2.4.2	Result-oriented and activity-oriented indicators determine performance in maintenance. Product performance is mainly determined by built-in reliability and maintainability metrics.
2.4.3	Successful maintenance depends on individual, social and organisation factors. These factors need to be supported by appropriate documentation and technical systems in a favourable environment. Effective communication between all elements (including the technical system) is essential.
3.1	One-off should-cost estimation is suitable for customer supplier relationships at “arm’s length”. Should-cost estimation is the prevailing approach used in PSS. By contrast, strategic management of costs focuses on the activities within the enterprise, across organisations.
3.2.1	Analytical methods require a detailed breakdown of the investigated cost object and known cost rates for each item. The total cost is determined by the summation of the cost of all items.
3.2.2	Associative, spending-based methods require significant knowledge about past comparable cost objects. The specific context can easily be lost when using forecast-based approaches.
3.3	<ol style="list-style-type: none"> Approaches to maintenance and PSS cost modelling focus on the technical system supported, not the organisation delivering and supporting it. Context matters when using cost estimation for planning and control current approach. Commonly costs are determined by the number of repair interventions over a period of time neglecting the specific context of the repairs.
3.4	The perspective taken on a phenomenon determines the rationale for making decisions. Based on the perspective taken the meaning something has changes and hence the options for taking action change too.

motivate the research presented in this work.

4.1 Findings

The findings from the literature review on PSS and cost estimation for PSS are summarised in Table 7. These include findings about the central role of maintenance for availability provision.

4.2 Mismatches between findings & need for research

The findings from Table 7 are abbreviated and related to each other, and to premises of this research outlined in the Introduction in Part I. The need for an approach to PSS cost estimation that reflects the long-term continuous involvement of an availability provider is highlighted by Settanni *et al.* (2014). As such, the purpose of cost estimation for PSS becomes one of ‘planning and control’. The mismatches between these premises, the characteristics of PSS, current cost estimation approaches to PSS and maintenance, and characteristics that need to be taken into account when investigating PSS, are summarised and discussed below.

Mismatch 1 The application of methods intended for relationships “at arm’s length” between a customer and a supplier does not fit the need for continuous involvement of *all* organisations delivering a desired outcome *together*.

Need 1 Cost estimation methods need to evolve to enable their *application across organisations*.

Mismatch 2 Using cost estimation for planning and control purposes requires detailed knowledge about the specific context. Current approaches tend to neglect context and rely on average costs for example for repair events or information about cost objects from the past.

Need 2 Cost estimation techniques need to be equipped to take the specific *context* into account.

Mismatch 3 Availability metrics are commonly defined by product characteristics. In this way, planning and control decisions can only focus on the technical system, despite availability being delivered through PSS which are socio-technical systems.

Need 3 To support a planning and control purpose, a PSS model needs to take into account the *socio-technical* character of PSS.

Mismatch 4 Maintenance activities are a critical enabler successful delivery of an outcome through PSS. Analysis of PSS requires a holistic approach,

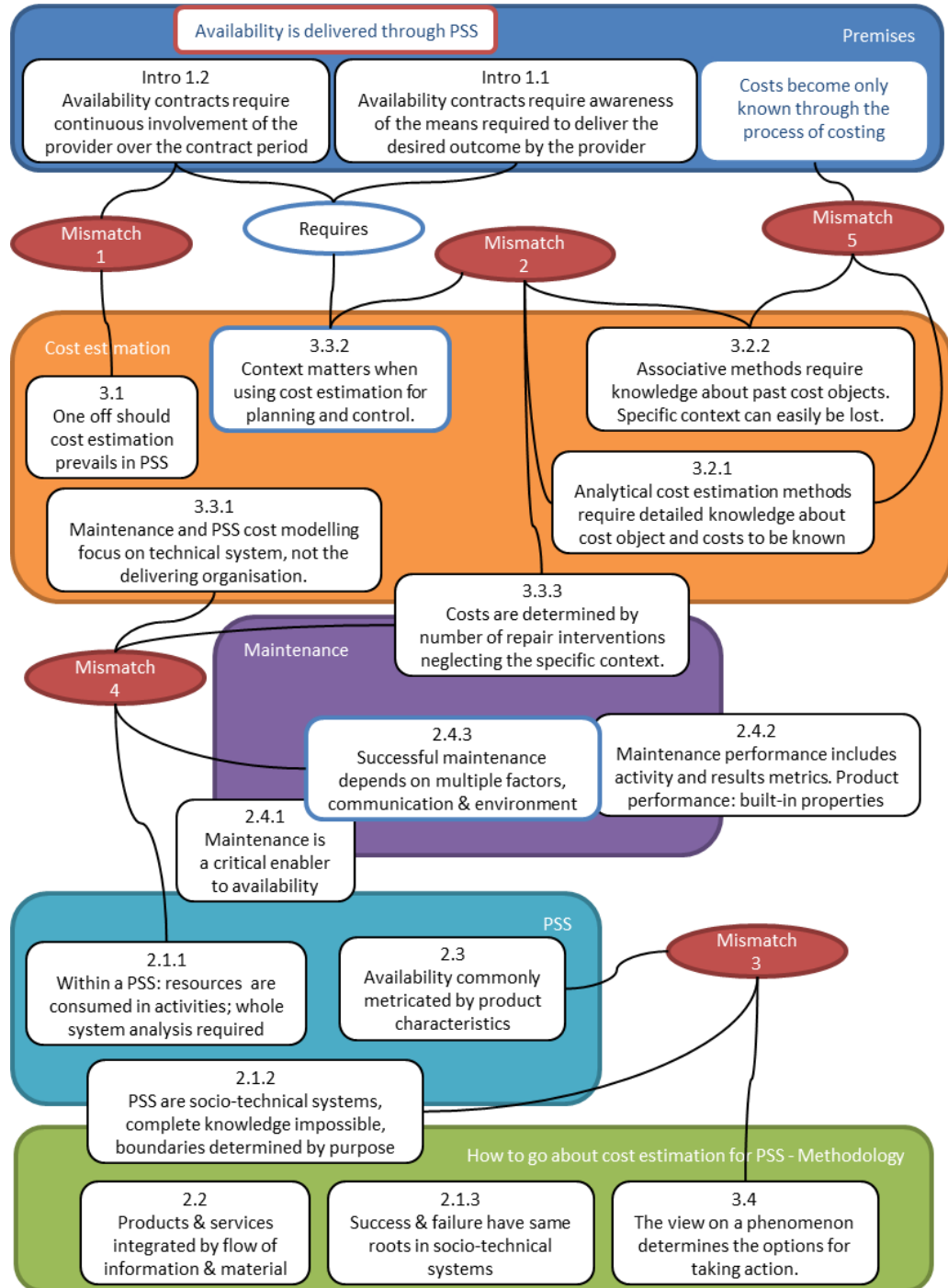


Figure 9 Relation of findings and identification of mismatches.

considering factors for successful maintenance, such as social, environmental, organisational and technical aspects. This is in contrast to current approaches where cost modelling for maintenance and PSS focus on the technical system and the number of repair interventions.

Need 4 A *holistic approach* to cost estimation for PSS is required that is able to incorporate social, organisational and other non-technical aspects of the delivery.

Mismatch 5 Current techniques used for estimating the cost of a PSS rely on given cost figures, neglecting the need for attributing costs to cost objects before moving to the mathematical analysis.

Need 5 A *costing* methodology, which is suitable for PSS is required.

The green box at the bottom of Figure 9 lays the foundations for the methodological choices that are discussed in the following Part “Methodology”, to address the needs outlined above.

This work addresses the needs 1 to 4 by proposing a qualitative model of a multi-organisational PSS based on the flow of information and material to represent the context availability is delivered in. Need 5 is addressed in this work through a process-based representation that allows the qualitative model to be used as a foundation for costing the PSS by means of qualitative modelling. In this way the structure of the PSS represented through the qualitative model is retained in the quantitative cost model. The quantitative modelling itself is addressed within another strand of the CATA research project.

5 Conclusion

Previous work has stressed that PSS result from the interaction of technical and social elements (Morelli, 2002). The socio-technical nature of a PSS has clear implications on how to investigate and make sense of it. However, the literature has paid scant attention to such an aspect in the qualification of PSS as socio-technical systems, especially when it comes to modelling the cost associated to delivering advanced services as availability.

Although not with reference to PSS, but with regards to the process of determining product cost it has been pointed out that due to the interdependencies between organisational activities, it would be misleading to

think that the effect of a series of independently taken decisions is equal to the sum of the expected effects of each individual decision (Cooper, 1990; McNair, 1990). Referring to manufacturing systems, Field *et al.* (2007, p. 23) explicitly state that cost is an emergent rather than an intrinsic or resultant property that arises within a specific context, and that cost modelling must be based on the transparent representation of this context. This view has been endorsed when costing a service (Edwards, 1999; Askarany *et al.*, 2010; Rotch, 1990) and more recently within the domain of PSS (Kimita *et al.*, 2009; Kimita *et al.*, 2012).

However, when it comes to advanced services, the reliability engineering approach to cost estimation tends to be adopted. These attempts to predict properties by reducing the system to characteristics of individual components, or aggregated system characteristics (e.g. Valerdi, 2011), clearly contradict the very foundation of what a system is considered to be. This is namely the inability to derive the system behaviour from its components in isolation, or by neglecting the constituent relationships. Such attempts confirm the observation made by Dekker (2011) that the analysis of systems often remains “*depressingly*” componential. To overcome this situation Settanni *et al.* (2014) suggest that costs emerge through the interplay of multiple components within a PSS. Nevertheless, the question “What is the system that brings costs into being?” remains open.

Figure 10 illustrates that understanding and actions are intertwined in a

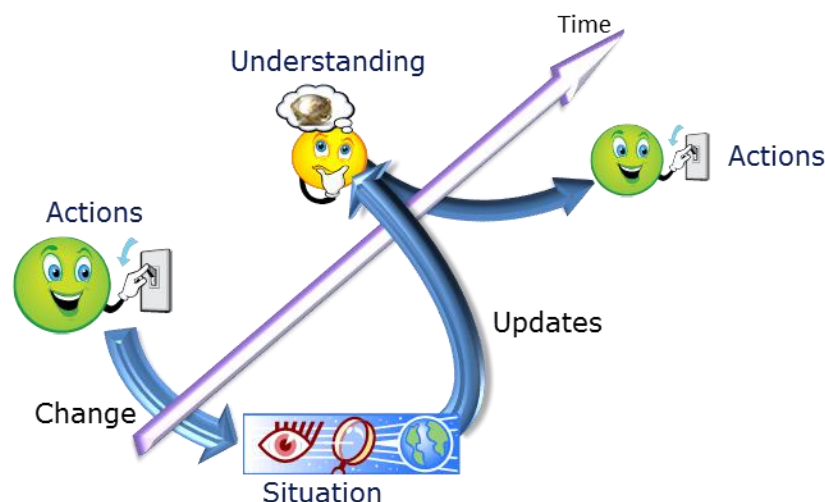


Figure 10 Actions are directed by understanding which evolves through update. (Adapted from Dekker, 2006, p. 136)

continuous process over time. Understanding evolves through continuous updates, taken from available environmental clues about the situation. Understanding is then tested through action in the real world to compare the expected with the actual outcome. Only when an understanding of a situation – including the interactions with the environment – is present can we determine what needs to be known to solve a problem (Ackoff, 1989). How well we understand a phenomenon determines our abilities to anticipate or infer the future behaviour of a system and accordingly whether the actions we undertake can lead to the results we desire. System understanding will only emerge through intellectual effort (Burge, 2010) and costing can only be insightful when it is based on an understanding of the whole delivery system.

Consequently, there is a direct link between a lack of understanding and representing the socio-technical system, and the inability to deliver a useful cost estimate. In short, **no system understanding, no meaningful cost estimate.**

There is however little guidance in the literature on modelling how the socio-technical character of PSS impacts the selection and application of appropriate methods. For example the dimensions presented by Cavalieri and Pezzotta (2012) for categorising the reviewed literature do not comprise the methods employed for collecting and analysing data, and whether the data was predominantly quantitative or qualitative or a combination of both.

In other fields, conceptual models have been proposed to depict the elements and relationships of the system under investigation. Although termed differently, for example static models in dynamic discrete event simulation (Whitman *et al.*, 1997) and qualitative maps in system dynamics modelling (Wolstenholme, 1999), these models provide initial understanding without the need for being in a format that is ready for computational analysis. Becker *et al.* (2010) endorse using conceptual models to support and guide offerings such as PSS. These examples suggest that qualitative models are appropriate for addressing the need to develop an understanding of the functional structure of the PSS through visualisation *before* setting up a model for computational analysis. However, the difficulties of modelling a PSS qualitatively should not be underestimated. This has recently been demonstrated by Mills *et al.* (2013) who employed enterprise imaging to represent a multi-organisation PSS supporting military aircraft.

PART III: RESEARCH METHODOLOGY

Tell me what you can hear, and then tell me what you see. Everybody has a different way to view the world.

Iron Maiden (2006)

Methodology concerns “the attempts to investigate and obtain knowledge about the world in which we find ourselves” (Flood and Carson, 1988, p. 269). Hence, the discussion in this section is about the view on the world, whether there is ‘a world’, what it means under which circumstances, and suitable methods for drawing conclusions about phenomena. With respect to PSS, their visualization and modelling are not unusual. However a more fundamental discussion concerning the ways of knowing about PSS is avoided in the specific literature. Hence, there is no clear guidance for practitioners how to approach PSS; with the exception of PSS design the approaches are heterogeneous and scattered across different fields. Several handbooks and other publications are dedicated to research methodology. However, different authors use different concepts in the methodological discussion, as shown in Table 8.

This Part structures the methodological aspects relevant for investigating socio-

Table 8 Concepts in the discussion of methodology.

Reference	Methodological concepts
Denscombe, 2010	Strategies, methods, analysis
Crotty, 1998	Epistemology, theoretical perspective, methodology, methods
Åsberg <i>et al.</i> , 2011	Ontology, epistemology, methodology, method, data
Creswell, 2014	Philosophical worldview, research design, research methods
Bryman, 2012	Type of theory, epistemology, ontology, strategy, design

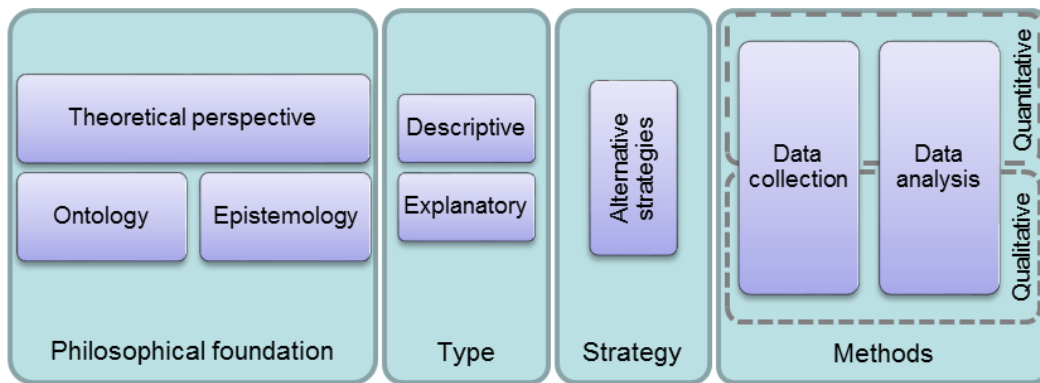


Figure 11 Research methodology overview.

technical systems and PSS in particular. Additionally, it is about the philosophical stance the research has been undertaken under and why it has been undertaken this way. It is shown how methodology governs the selection and application of methodical practices (Harrington, 2005). As such this Part represents one of the contributions of this thesis to the existing body of knowledge. Figure 11 shows how the concepts from Table 8 are combined in this work to structure the discussion on the methodological choices.

1 Philosophical foundation

A dictionary definition of philosophy is that philosophy inquires about the most general and abstract concepts of the world such as meaning and truth (Oxford University Press, 2008). Hence, the philosophical foundation of a research methodology concerns the theoretical perspective taken in carrying out the research this research. This perspective itself is shaped by the underlying ontology and epistemology. These concepts play a crucial role for the creation of understanding being rooted in how we make sense of the world. Perhaps, one of the most effective ways of expressing this is in the words of Dekker (2011, p. 5):

“If the worldview behind these explanations remains invisible to us, [...] we will never be able to discover just how it influences our own rationalities. We will not be able to question it, nor our own assumptions. We might simply assume this is the only way to look at the world. And that is a severe restriction [...]. Applying this worldview, after all, leads to particular results [...]. It necessarily excludes other readings and other results. By not considering those (and not even

Table 9 Objects, sciences and their principles of explanation (adapted from Moses and Knutsen, 2007, p. 168).

Object	Properties	Science	Principle of explanation
Inanimate	Mass and extension	Physics	Causality
Animate	Mass and extension		
Humans	+ vital force + will and reason	Social sciences	Volition, interest, meaning, rules, institutions, praxis

knowing that we can consider those alternatives) we may well short-change ourselves."

Similarly, Crotty (1998, p. 38) points out that Paul Feyerabend – one of the most famous philosophers of science in the twentieth century (Preston, 2012) – demanded that scientists test their perceptions and recognize the viewpoint they are taking. Dekker *et al.* (2012) critically review the philosophical foundations in ergonomics, a field that is particularly concerned with the interplay between humans and technical systems. The authors conclude that the epistemological foundations of the domain prevent it from embracing current challenges and advocate the integration of social sciences and humanities in ergonomics. Table 9 shows the principles of explanation employed by different sciences and which properties of the object under investigation are considered.

Luna-Reyes and Andersen (2003) point out the contribution of the social sciences for the methods of conceptualising systems dynamics models. However, it is the author's opinion that such contribution should not be restricted to the methods. At least equally important are the philosophical foundations and the consequences that arise from the underlying worldview in terms of what can be known and which conclusions can be drawn from an investigation. One insight is that facts and truths within the social sciences can at best be described as perspectival (Rosenblatt, 2002, p. 893).

1.1 Ontology

Ontology is the theory of being, it concerns what the world is, or what it contains (Flood and Carson, 1988; Crotty, 1998). Ontological enquiry can be about the entities believed by people to exist, as well as about what social life consists of (Harrington, 2005, pp. 324–325). Referring to reality as 'the world', Flood and

Carson (1988, p. 269) identify “*realism*” and “*nominalism*” as the two opposing ontological standpoints. According to realism, reality is a given ‘out there’ of objective nature, that imposes itself upon the individual’s consciousness. An opposed view is nominalism, according to which reality is a product of individual consciousness, that is, of the individual’s own mind.

More specific on the nature of social entities rather than reality as a whole is the distinction between “*objectivism*” and “*constructionism*” proposed by Bryman (2012, p. 32). Within objectivism social entities are considered objective entities having a reality that is independent of social actors. By contrast, social entities are considered to be built up from the actions and perceptions of social actors in a constructionist viewpoint.

Crotty (1998, p. 10) cautions that realism should *not* be confused with objectivism; the latter referring to the existence of *meaning* in objects independently of consciousness and therefore touching epistemological rather than ontological questions. For Crotty, the ontological discussion is meaningful only in combination with the discussion on epistemology which is the subject of the following section.

The use of the term ‘ontology’ in other fields than philosophy, and the terminological ambiguities that may arise are discussed by Gilchrist (2003).

1.2 Epistemology

Ways of “*understanding and explaining how we know what we know*” is the essence of epistemology (Crotty, 1998, p. 3). Its German translation *Erkenntnistheorie* is, more explanatory terminology-wise, but hampered by the fact that there is no direct translation of the word *Erkenntnis* to English (Gabriel, 2013). It comprises concepts such as insight, recognition, knowledge, understanding and making sense. Accordingly, epistemological questions concern how we gain understanding about the world or a situation, how we communicate this knowledge and the forms of knowledge that can be obtained (Flood and Carson, 1988, p. 269).

Similar to what has been discussed in the previous section on ontology, there are differing views on how to describe epistemological standpoints. For example Schultze and Stabell (2004) propose a framework based on duality versus dualism

Table 10 Epistemology dimension: dualism versus duality (based on Schultze and Stabell, 2004, p. 554).

	Dualism (either or)	Duality (both/and)
Framing of the phenomenon	Object is frozen in time	Object is continuously shaping and being shaped by situated practice
Assumption about causality	Uni-directional; deterministic	Cyclical; circulating, emergent
Assumptions about the world	Finite; completely knowable	Infinite within parameters, i.e. constantly changing yet staying the same; not completely knowable
Ability to handle contradictions	Contradictions do not exist, they are merely a sign that taxonomies and models are not sufficiently granular	Embraces contradictions and paradox; considers opposing forces operating simultaneously

to discuss the nature of knowledge, as shown in Table 10. An epistemological standpoint of duality acknowledges the role of practice for shaping phenomena in their context. Conversely, dualism favours an object-like interpretation of the phenomenon (Schultze and Stabell, 2004, p. 553).

Following Crotty (1998), the meaning of objects and the possibility to discover objective truth is what determines the epistemological standpoint. Crotty distinguishes between three epistemologies: objectivism, constructionism and subjectivism. However, he also warns that such epistemologies should not be considered as “*watertight compartments*” (Crotty, 1998, p. 9). In an objectivist epistemology objects hold meaning independent of the presence of consciousness. Accordingly, there is a ‘right’ way of enquiry to discover the objective truth. This view is opposed by constructionism which maintains that meaning cannot be discovered but is constructed. From a constructionist viewpoint, meaning, or truth, comes into being through the engagement of humans with the world. In an epistemology of subjectivism, the interaction with the world is not a necessity to create meaning, rather, meaning is placed on the object independently of the object.

Terminological ambiguities arise when looking at the extremes of epistemological viewpoints as “*positivism*” and “*antipositivism*”. Flood and Carson (1988, p. 269) use positivism and antipositivism to point out that knowledge can be seen as hard and tangible, or transcendental and experiential, respectively. By contrast, according to Blue *et al.* (2014) ‘positivism’ reflects a specific ‘worldview’, or

theoretical perspective (Crotty, 1998) which is discussed in the following subsection.

1.3 *Theoretical perspective*

The theoretical perspective is shaped by the epistemological and ontological standpoints. Hence, it reflects the 'worldview', i.e. what we consider the world to be, and how we can (and do) gain knowledge about it. A person's worldview comprises expectations, assumptions and experiences that are integrated with how the person makes sense of the world (Vaughan, 1997).

Also with regards to the theoretical perspective, the literature uses different terminology to express similar concepts. *Positivism* is commonly used to express a view that the world can be objectively observed and described (McNeill, 1990; Crotty, 1998). It implies that the only valid source of knowledge comes from experimental observation and other sources of insight are incapable of rigorous validation (Harrington, 2005, p. 325). That same view is termed "*postpositivism*" by Creswell (2014). Crotty (1998) discusses postpositivism as well as other forms of historical and contemporary positivism. Moses and Knutsen (2007), also discussing positivism, introduce the term "*naturalism*" as a synonym for positivistic science. The characteristics of a naturalist approach are outlined in Table 11. The naturalist characteristics are contrasted with the constructivist approach that, according to Moses and Knutsen (2007), summarises the theoretical perspective opposing naturalism. Crotty (1998, p. 66), in comparison cites "*interpretivism*" as the contra-distinction to positivism, in particular to explain social and human reality. Further theoretical perspectives following the interpretivist viewpoint comprise symbolic interactionism, phenomenology and hermeneutics (Crotty, 1998, p. 5).

In addition to postpositivism and constructivism Creswell (2014, p. 6) introduces the "*transformative*" worldviews and "*pragmatism*". Transformative studies seek to confront social oppression and recognise that research inquiry is always intertwined with politics. Feminist research as well as the works from Marx, Habermas and Adorno can be placed in this theoretical perspective (Creswell, 2014, p. 9). Shown in Table 11 as normative studies (see 'Objectivity'), the constructivist viewpoint according to Moses and Knutsen (2007) can accommodate

Table 11 Comparison of the naturalist and the constructivist approach
(adapted from Moses and Knutsen, 2007, p. 287).

View on	Naturalism (Positivism)	Constructivism
World	Objectively real / permanent	Human construction / changeable
Man	Man is similar to material objects (e.g., man has mass and extension), but with a capacity to reason. Man can be as meaningless (literally), as will / agency is generally downplayed. Constant and predictable.	Like naturalists but with greater focus on will, agency, reason and empathy: men and women are creatures of their context, and contribute to its creation. Malleable
Knowledge	Cumulative and based on sensual experience (primarily observation)	Knowledge is overlapping: it advances, retreats and moves sideways. Embraces a wider epistemological field comprising observation, authority, reason, empathy.
Theory	Theory is an aid to explaining and is used to reveal patterns in the world. Theories are clusters of objective laws.	Theory is an aid to understanding and is used to reveal contingent phenomena. Theories are products of the human imagination.
Truth	Subscribes to the correspondence theory: a statement is true when it corresponds to the facts in the real world. Fixed.	Truth is derived from changing constellations of power and perspectives. Fleeting.
Objectivity	Following Hume: studies about how the world <i>should</i> be ¹ should be banished.	Normative framing is important, unavoidable, and should be brought out into the open.
Context	Context is not important in itself: the world can be manipulated in a mechanical fashion to reveal causal relationships.	Context is central and must be protected in order to access meaning.

¹ "Normative", as defined in Harrington, 2005, p. 324

such studies. The transformative worldview is therefore not considered here as a theoretical perspective in addition to the naturalist/positivist and constructivist.

A similar reasoning can be applied to Pragmatism which, as summarised by Creswell (2014, pp. 10–11), is associated with the selection of mixed *methods*, rather than specific ontological and epistemological standpoints. In opposition to such argument, the importance of the worldview underlying the research, as was previously highlighted at the beginning of this section, cannot be overcome by simply 'changing the subject', as suggested by Rorty (quoted by Creswell, 2014, p. 11). Also, following Åsberg *et al.* (2011), the quantitative, qualitative (or mixed) methods discussion is a matter of data collection and analysis rather than a methodological one. Accordingly, here, pragmatism is not considered a

worldview that builds on the ontological and epistemological discussion in the previous sections.

To summarize, the positivist and the constructivist viewpoints are identified as opposing worldviews underlying the selection of research strategy and methods in this research.

1.4 *The theoretical perspective in the literature*

There is evidence that in the field of engineering a positivistic worldview is predominantly followed without explicitly stating such standpoint (Vaughan, 1997, pp. 201–202; Blue *et al.*, 2014, pp. 9–10). Insights such as PSS being social constructs (Morelli, 2002) are addressed on a methodical level only. For example Durugbo *et al.* (2011, p. 1200) are almost exclusively concerned with modelling the flow of information and communication between people and functions to ensure the functioning of organisations. There is no mentioning of epistemological or ontological consequences when considering a PSS as a social construct. Similarly, Vasantha *et al.* (2011) quote Morelli (2002) and Durugbo *et al.* (2011) but take no further notice of what social constructs might mean for PSS modelling methodologies. Also, in their conclusion Vasantha *et al.* (2011) use the term ‘ontology’ without specifying its meaning. However, it is reasonable to assume that the meaning they refer to is not related to the theory of being but rather to concepts and their relationships for computational specifications as for example defined by Tom Gruber in Perakath *et al.* (1994). Such a definition of ontology is particularly recurring in the Computer Science community, and it has been used also by Annamalai *et al.* (2011) who propose an ontology of PSS.

Accompanying the prevailing positivistic worldview in engineering is a belief in objectivity (Blue *et al.*, 2014, pp. 9–10). For example Sinkkonen *et al.* (2013) strive for an “*objective cost model*” but miss how such objectivity can hold considering the limitations the authors discover (ambiguous terminology and differing cost allocation methods across the investigated cases), and with respect to the methods they employ. Another indication of a believe in objectivity is the aspiration to “*understand true whole life cost of a [PSS] contract*” (Meier *et al.*, 2010a, p. 614), or “*the true ‘total cost of ownership’*” (Ellram, 1995, p. 5). This line of reasoning can be especially found in those applications of artificial intelligence within cost estimation (Gitzel and Herbort, 2008; Deng and Yeh, 2010; Chou *et al.*, 2011) and

more clearly emerges when those techniques are compared to other approaches (Caputo and Pelagagge, 2008; Liu *et al.*, 2008). In such cases, it is thought even beneficial for the accuracy of the cost estimate that the analyst is relieved from making subjective choices for example regarding the mathematical functional form of the cost estimation model. The underlying assumption is that there are *true costs* and that these can be discovered.

Nevertheless, also in engineering and cost modelling it is acknowledged that ‘truth’ might not be what it seems. With regards to cost modelling, Hansen and Mowen (2003, p. 33) state that:

“Our notion of accuracy is not evaluated based on knowledge of some underlying ‘true’ cost. Rather it is a relative concept and has to do with the reasonableness and logic of the cost assignment methods that are being used.”

An extended discussion of ‘truth’ in the construction of cost models can be found in van der Merwe (2007a; 2007b).

In reliability engineering, a field which is statistical-modelling intensive, Evans (1999, p. 105) points out that:

“The data are often what somebody said that somebody said. They can be forms that are filled out by repair-people or by people being interrogated. When the responses are verbal, they are rarely what people think believe - but what these people think they ought to say. If data are forms filled out by repair people, they can be the truth, but they indicate replaced items, not failed items; they can also be lies, if there is sufficient incentive, to lie.”

It is noteworthy that such view is stated in an ‘Editorial’ and not a research article, and it still reflects a significantly different worldview to constructivists who “*aim to get a meaning, not a truth*” (Charmaz, 2000, p. 526).

In ergonomics Dekker *et al.* (2010) raise fundamental questions about truth and objectivity. By contrast, the discussion on cost estimation for advanced services and PSS modelling is currently not concerned with its philosophical foundations.

1.5 Stance taken

Starting from the ontological viewpoint, this work recognises the existence of objects, such as avionics equipment outside the human mind. However, it is also recognised that the meaning of an object or an observation is dependent on the context and the observer. An example is whether activities performed on a piece of equipment *declared* as defective lead to the equipment being *categorised* as defective or not (Blackwell and Hausner, 1999). An epistemology of duality accommodates such view, and it also supports the view that opposing phenomena are not mutually exclusive but complement each other. Such is the case for success and failure of a socio-technical system in delivering its intended results being rooted in the same origins (Hollnagel, 2012, p. 22). Being concerned with practices, this research has to take into account that in engineering judgments are made in conditions of imperfect, i.e. incomplete knowledge (Vaughan, 1997, p. 203). Furthermore, within socio-technical systems there is no reason to believe that complete knowledge can be obtained at all (Hollnagel, 2012, p. 4). Hence, the assumptions underlying a positivistic standpoint that the world as it is can be observed and described cannot be held. Furthermore, the qualification of a PSS as a social construct (Morelli, 2002), i.e. an entity that cannot be observed in the natural world, but rather comes into being through the interactions among humans and humans with objects cannot be captured adequately through a positivistic lens. Therefore, this research is undertaken adopting a constructivist approach, recognising “that people may look at the same thing and perceive it differently” (Moses and Knutsen, 2007, p. 11).

2 Types of research

According to Blessing and Chakrabarti (2009, p. 18) research can be distinguished by its purpose being a description of a phenomenon or a prescription of how a situation *will* unfold; hence the distinction between *descriptive* and *prescriptive* research. Three stages of research (named “*Descriptive I, Prescriptive, and Descriptive II*”) are outlined in the Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009, p. 15). Similarly, Yin (2009, pp. 6–7) suggests that research develops through an exploratory, descriptive and explanatory phase. The underlying commonality is that a research project has different stages, and at each stage different insights are provided. Vincenti (1990, p. 197) uses the same terminology as in the DRM to express knowledge about “*things as they are*”, i.e.

descriptive knowledge, and how “*things should be to attain a desired end*” as prescriptive knowledge. Both explanatory and prescriptive research require a description of the phenomenon under investigation – see, respectively, McNeill (1990, p. 10) and Blessing and Chakrabarti (2009, p. 18). Therefore, the distinction between both types can be blurred (McNeill, 1990, p. 10).

The type of study also determines whether an *inductive* or *deductive* reasoning is applied (Åsberg *et al.*, 2011); the former seeking to derive regularities from the observations and the latter testing theory (Bryman, 2012, p. 24). An outline of inductive, deductive and abductive reasoning can be found in Roozenburg (1993). In the remainder of this work the distinction is made between descriptive studies that start from the observation, and explanatory studies that are based on an initial theory that contains the main concepts and their relationships.

2.1 *Descriptive and inductive research*

Descriptive studies aim to describe a phenomenon in detail to give an account for *what* is happening (McNeill, 1990, p. 9). They contribute to the understanding of a situation by identifying factors, concepts and relationships among these. In this way descriptive studies are a precondition for research that aims at improving situations or support practical applications (Blessing and Chakrabarti, 2009).

Descriptive studies that are interested in the qualities of a phenomenon tend to follow an inductive approach where theory is derived from the observations (Creswell, 2014). Induction is a process of deriving general regularities from accumulated specific instances (Crotty, 1998, pp. 31–32). Hence, inductive approaches use the collected data and its analysis to derive theory. Nevertheless, inductive studies also require a preliminary understanding of the phenomenon that guides the collection and analysis of the data (Bryman, 2012, pp. 26–27).

2.2 *Explanatory and deductive research*

The explanation of phenomena, frequently coupled with quantification, based on existing theory is what characterises explanatory and deductive studies (Creswell, 2014, p. 59). Moses and Knutsen (2007, pp. 183–184) highlight the differences in ‘explanation’ between the social and the natural sciences:

“Natural science hinges on the principle of Erklären; it seeks to explain natural phenomena in terms of cause and effect. The human sciences (and the budding social sciences) involve the principle of Verstehen; they seek to understand social phenomena in terms of relationships.”

The relationship to theory is determined through the process of deduction which starts with the formulation of a hypothesis based on existing knowledge. Such hypothesis (or hypotheses) is then scrutinized through empirical evidence. This is followed by an inductive stage where implications of the findings on the initial theory are assessed and the theory is adjusted as required (Bryman, 2012, pp. 24–25).

2.3 Research types described and applied in the literature

When it comes to cost estimation of long term availability contracts for industrial applications common approaches are typically based on reliability and cost data provided by industrial partners (Jazouli and Sandborn, 2011; Feldman *et al.*, 2009; Jacopino, 2007; Scanff *et al.*, 2007; Bowman and Schmee, 2001). These studies use real world data, apply predefined computational techniques to them and seek validation through a comparison of their numerical results with quantities supplied by the industrial partners. These studies can be regarded as *“theory confirming”* (Åsberg *et al.*, 2011), being of explanatory and deductive nature. Since none of these references is concerned with representing the delivery system, these studies provide little insights about *how* availability is delivered in the respective context.

The lack of context is addressed in the literature, but only scarcely. With reference to manufacturing, Field *et al.* (2007) explicitly warn that cost should not be regarded as a simple intrinsic property of a product (like a factor price) but as an emergent property dependent upon the context within which products are designed and delivered. With reference to service costing, Sharman (1999, pp. C3–3) highlights the need to understand the components of both financial and nonfinancial measurements in the context of the whole organisation as a system. Dodson (1979, pp. 2–5) points out that the cost analyst must have an understanding of the process he is studying, and that in the absence of such an understanding the application of statistical procedures to quantitative data can be merely *“an organized way of going wrong with confidence”*.

In the field of PSS in aerospace, context provided in descriptive studies can be found in the form of case studies, for example Johnstone *et al.* (2009) (see Part III section 3.7 for further case studies in PSS and cost engineering). Specifically related to availability provision in aerospace is the work by Mills *et al.* (2013). Although not explicitly qualified as ‘descriptive’, the study sets out to describe and represent a situation rather than testing a predefined theory.

2.4 Selected type

For this research a descriptive and inductive approach is chosen. This choice is a reflection of the research aim that seeks to identify the processes and relationships among them that are involved in delivering an advanced service. In particular in the field of cost engineering where explanatory studies dominate there is a need for descriptive studies that provide insight into the specific context. Vincenti (1990, p. 94) underlines the need to carefully assess the suitability of mathematical theories for the situation at hand:

“The background for this reversal (that is, the quarter century in which the aeronautical community was blinded by concern for the long-period oscillation) provides a cautionary example of how preconceived, uncritical use of mathematical theory can mislead in practice.”

3 Research strategy

The research strategy describes the broad plan of action for the achievement of a specific goal of the research (Denscombe, 2010, p. 3). The strategy informs the selection of specific methods for data collection and analysis and links their choice to the outcome desired by the researcher (Crotty, 1998, p. 3). This stage of research methodology is expressed in different terms in the literature, for example “*research design*” (Bryman, 2012, p. 50; Creswell, 2014, p. 5), “*methodology*” (Crotty, 1998, p. 3) and “*methods*” (Moses and Knutsen, 2007; Yin, 2009). Similarly, the strategies, research designs, methodologies, and methods vary depending on the reference. The strategies outlined in the following subsections mainly follow the terminology proposed by Denscombe (2010).

3.1 *Survey research*

Central to survey research is the quantification or a numeric description of the phenomenon under investigation. Survey research intends to generalise from a sample to a population, in particular for testing theory (Creswell, 2014, p. 13; Denscombe, 2010, p. 5). Being highly structured, it is unlikely that survey research supports the discovery of anything that has not already been anticipated by the researcher (Sapsford, 2007, p. 14). Accordingly, survey research can be typified as ‘explanatory’ or ‘theory testing’. Since this work is of descriptive nature the survey strategy is not further elaborated on here.

Common methods for data collection include questionnaires and structured interviews (Creswell, 2014, p. 13). Hawkins and Orlady (1993, pp. 229–230) caution that the value of a survey strongly depends on the design of the survey programme and the questionnaire. They suggest a survey design process that includes upfront information gathering, a trial study and iterative refinement of the questionnaire.

3.2 *Experimental research*

Experimental research aims to identify the cause of something through the observation of specific factors (Denscombe, 2010, p. 5). Classical experiments are based on the manipulation of independent variables to determine their effect on the dependent variable, testing an underlying hypothesis (Blessing and Chakrabarti, 2009, p. 265). Two groups, one receiving a specific treatment, and the other not, are compared according to their score on a specific outcome (Creswell, 2014). Therefore experiments require the researcher to have control over the context (Yin, 2009, p. 8). Quasi-experiments allow researchers to draw conclusions on cause-effect relations even though not all requirements for an experiment are met, as for example the random assignment of subjects to the treatment (Creswell, 2014, p. 13) or representativeness of the target population (Blessing and Chakrabarti, 2009, p. 265).

Control over the conditions during an experiment has also consequences for the insights the generated results can provide.

With regards to electronic equipment, Sandborn (2013, pp. 221–234) provides an illustrative example on how reliability metrics such as the Mean Time Between

Failure (MTBF) are computed in test-rig conditions. However, characterising an *operative* technical system by its MTBF requires the operating conditions such as environment and mission duration to be known (Blackwell and Hausner, 1999, p. 271). Therefore, using MTBF from test-rig conditions can be misleading when drawing conclusions while the technical system is operated in ‘real world’ conditions.

3.3 Grounded theory

Grounded theory is an approach for generating theory about human interactions in specific settings through qualitative data analysis. As such grounded theory is distinctly different from strategies aiming at testing theories and strategies suitable for descriptive studies. A core characteristic of the grounded theory approach is the emphasis on empirical fieldwork and the close link between the explanations the developed theory provides to practice (Denscombe, 2010, pp. 106–124). Bartlett and Payne (1997, p. 183) outline the process from data collection through the analysis to building theory. The data analysis comprises the identification of schemes (coding) within the transcribed data, as for example from interviews or observations, and the continuous creation of memos that contribute to linking the codes and integrating codes into theory (Bartlett and Payne, 1997).

Table 12 Advantages and disadvantages of the grounded theory approach according to Denscombe (2010, pp. 121–123).

Advantages	Suitable for small-scale research; Recognized rationale and justification for qualitative research; Systematic way of analysing qualitative data to develop concepts and build theory; Adaptable to multiple methods of data collection; Practice-oriented; Theory development from the data; Explanations are grounded in reality; Suited for the exploration of new fields and ideas.
Disadvantage / criticism	Planning ahead difficult; Focus on specific context might ignore influences from external factors; How to deal with ‘open mindedness’; Data analysis can be daunting; Positivistic tendencies; Empiricist through ignorance of larger scale theories in favour of empirical data; Generalizations are rather abstractions than being transferable to a larger population; Grounded theory approach as justification for “sloppy” research.

Advantages and disadvantages of adopting a grounded theory approach following Denscombe (2010, pp. 121–123) are summarised in Table 12.

Charmaz (2000, p. 528) addresses opposing epistemological perspectives in grounded theory research and promotes a constructivist approach that explicitly recognises the developed theory as a construction rather than an objective product.

3.4 *Action research*

In action research the researcher takes an active role in developing and implementing a solution to a practical problem, as for example in planning and introducing policy changes (Denscombe, 2010, p. 6; McNeill, 1990, p. 10). Building on the cyclical relationship between experience and action (Checkland and Scholes, 1999, p. 3) action research undergoes an iterative process involving planning, actions, research, reflection and evaluation (McNeill, 1990). Action research, being situated in practice, involves participation of practitioners. This has such advantages as enhancing the appreciation of the researcher of practice. However, there are also challenges involved when adopting an action research approach. For example ethical issues can arise when colleges become the object of investigation (Denscombe, 2010, pp. 132–135). Additionally, the deep involvement of the researcher in a specific context can lead to the research overemphasizing local aspects (Blessing and Chakrabarti, 2009, p. 273).

3.5 *Ethnography*

Ethnography has its roots in anthropology and sociology. Ethnographic enquiry is concerned with language and behaviours for cultural practices and traditions within a culture in its natural setting (Denscombe, 2010, p. 5; Creswell, 2014, p. 14). In ethnographic studies the purpose of talk is associated with what people mean. By contrast, the identification of what is done with talk is the focus of an ethnomethodological approach (Payne, 1999, p. 99). Ethnographic studies commonly involve extended periods of participant observation (Harrington, 2005, p. 320). An example for the use of historical ethnography in the analysis of socio-technical systems is Vaughan (1997) who reconstructs the situation before the explosion of the Space Shuttle ‘Challenger’ from the perspective of those involved.

3.6 Case Study

In case studies the researcher analyses a bounded case, such as a program, a specific event or activity to gain an in-depth understanding about the phenomenon in its natural setting (Creswell, 2014, p. 14). Case studies are particularly useful when the phenomenon under investigation cannot be separated from its context and the researcher has little or no control over the set of events (Yin, 2009).

One of the characteristics of case studies is that they are able to provide insights into the intricacies of social settings through the discovery of relationships and processes. Hence, case studies can provide a more holistic view of how elements are interlinked, rather than considering elements in isolation. Additionally, case studies favour a focus on *how* outcomes are delivered through (social) processes (Denscombe, 2010, p. 53).

Denscombe (2010, p. 55) highlights the versatility of case studies, being suited for discovery-led research, for example descriptive studies, as well as theory-led research that seeks to explain causes of events within a specific setting. Eisenhardt (1989, p. 548) suggests the case study approach for theory building when current perspectives on a topic do not seem adequate, or when they conflict with each other. Problematizing the issue of knowledge creation through generalisation, Flyvbjerg (2006, p. 227) stresses the value of descriptive case studies that do not *attempt* to generalise. Through the selection of the case (or cases in a multi-case study (Yin, 2009)), for example an extreme or a critical case, conclusions might be drawn for settings other than the one investigated (Flyvbjerg, 2006, pp. 229–233).

Denscombe (2010, p. 14) summarises the use of case studies in discovery led research:

- A description of example events, processes and relationships occurring in the specific setting;
- The exploration of key issues such as problems and opportunities affecting people in the setting;
- A comparison of settings to learn from similarities and differences.

In general, case studies can rely on different types of data and methods for data collection and analysis (Denscombe, 2010, p. 54; Creswell, 2014, p. 14)

3.7 Strategies described and applied in the literature

Table 13 shows strategies employed in cost engineering and PSS research, as they are stated in the respective reference. The two most widely used strategies are survey research and case studies. In some cases strategies are combined, for example James (2003) uses grounded theory in a case study. Experimental and ethnographic strategies were not identified in the field of cost engineering and PSS research. Theory confirming studies such as those mentioned in the previous section using the likes of simulation to compute quantities for example ‘cases’ such as a specific product (for example Scanff *et al.*, 2007) are not included in Table 13.

Two of the references identified in Table 13 cover PSS *and* cost engineering (Lindahl *et al.*, 2014; Datta and Roy, 2010). While Lindahl *et al.* (2014) use three case studies, none of these represents an advanced service as defined by Baines and Lightfoot (2013). Only the study by Datta and Roy (2010) is specifically concerned with availability provision. However, from a cost engineering perspective the authors are interested in the cost estimation techniques employed, not with how availability is delivered. Such a delivery is dealt with separately in another paper, with no reference to costing (Datta and Roy, 2011).

In the cost engineering domain, studies that declare to follow an ABC approach are those that investigate how the specific outcome is delivered, for example

Table 13 Research strategies in cost engineering and PSS research
(references can be assigned to more than one category).

Strategy	Cost engineering, costing	PSS, servitization
Survey	Askarany <i>et al.</i> , 2010; Tysseland, 2008; Dunk, 2004; Serpell, 2004; Assaf <i>et al.</i> , 2002; Akintoye and Fitzgerald, 2000; Fiorello, 1973	Aston Business School, 2013; Edison and Murphy, 2012; Jagtap <i>et al.</i> , 2007; Ferrin and Plank, 2002
Experimental		
Grounded theory	James, 2003	
Action research	Nicolini <i>et al.</i> , 2000	Evans <i>et al.</i> , 2007
Ethnography		
Case study	Lindahl <i>et al.</i> , 2014; Schulze <i>et al.</i> , 2012; Datta and Roy, 2010; Lindholm and Suomala, 2007; James, 2003; Börjesson, 1994	Lindahl <i>et al.</i> , 2014; Maull <i>et al.</i> , 2013; Mills <i>et al.</i> , 2013; Ng <i>et al.</i> , 2012; Lockett <i>et al.</i> , 2011; Datta and Roy, 2011, 2010; Johnstone <i>et al.</i> , 2009; Evans <i>et al.</i> , 2007

Schulze *et al.* (2012) and Lindholm and Suomala (2007). Korpi and Ala-Risku (2008) review case studies in life cycle costing for products. The dimensions of their case analysis comprise the operating environment, the purpose of the analysis and the life cycle costing methods employed.

Case studies about PSS tend to be descriptive, for example Johnstone *et al.* (2009) and Ng *et al.* (2012) are concerned with *how* companies in aerospace operationalise combined product service offerings. Johnstone *et al.* argue that the insights sought cannot be achieved through survey research: *“For example, given the conceptual confusion surrounding the notion of P-S [Product-Service], it would be difficult to check that respondents are interpreting questions in standard ways. Use of quantitative indicators to ‘measure’ P-S is therefore inherently problematic, and using raw outcomes as indicators may reveal little about how P-S is understood and enacted.”* (2009, pp. 525–526)

3.8 Selected strategy

The insights sought, aiming at a real world problem, an existing setting in which availability is delivered, lead to an exploratory and descriptive research approach under conditions that cannot be controlled by the researcher. Snook (2002, p. 223) emphasises the need for an approach that can provide a holistic view to capture that mechanisms that span across boundaries of individual groups or organisations. It is therefore necessary to develop an in-depth description of the processes, their relationships and events constituting the phenomenon under investigation as they play out in practice. As described above in section 3.6 a case study can provide such insights and is therefore selected for this research.

4 Methods for data collection

Methods stand for ‘ways of doing something’ (Åsberg *et al.*, 2011, p. 409). Hence, methods for data collection describe the process of gathering information about the phenomenon under investigation.

4.1 Interviews

In their review and comparative analysis of knowledge elicitation techniques Dieste and Juristo (2011) conclude that interviews are the most efficient techniques to gather insight from people into a domain. Denscombe (2010, pp. 174–178)

distinguishes interviews by the degree of structure that is imposed and the number of people being interviewed at the same time. Being highly standardised, structured interviews provide in pre-coded answers and are often associated to survey research. (Denscombe, 2010, pp. 174–175). By contrast, in semi-structured interviews the researcher uses a guideline to cover the issues he or she is interested in but is more flexible and allows the interviewee to develop ideas. Questions in semi-structured interviews are open ended rather than predefined as in structured interviews. The transition towards unstructured interviewing is gradual and depends on how much the interviewer reduces his role to introducing a topic and then letting the interviewee pursue his own line of thought (Denscombe, 2010, p. 175).

Pidgeon *et al.* (1991) argue that semi-structured interviews can provide a rich representation and through thorough analysis provide a ground to further develop theory. Similarly, Cooke (1994) concludes that less structured methods to gather knowledge from experts lead to richer outputs. In their case study within a manufacturing organisation Naylor *et al.* (2001) adopt semi-structured interviews to gain insights into *how* and *why* activities are carried out the way they are. Similarly, Followell (1995) highlights the “*real and extraordinary*” insights interviews provide about the activities and environments related to the failure of external aircraft stores.

In terms of number of interviewees per interview Denscombe (2010, p. 176) highlights the advantages of one-to-one interviews from a practicality perspective including the interviewer’s ability to control the interview, as well as transcription of the interview recording.

Significant practical disadvantages Denscombe (2010, p. 193) identifies with interviews concern the time required for data analysis and the open format of generated data that can be overwhelming and confusing to the researcher.

Group interviews and focus groups on the other side offer the chance to get more than one viewpoint at the same time, and to benefit from group dynamics. In focus groups the researcher’s role can be identified with that of a moderator rather than the focal point, as is the case in group interviews (Denscombe, 2010, pp. 176–177). Also group interviews and focus groups can be more or less structured (Fontana and Frey, 2000, p. 651).

The data generated from interviews can comprise recordings such as audio or video, and notes taken during the interview process or in retrospect (Denscombe, 2010, pp. 186–188).

4.2 Questionnaires

Questionnaires are commonly associated to survey research and used as means for the collection of quantitative data of a potentially large sample (Blessing and Chakrabarti, 2009). The design of a questionnaire strongly influences its usefulness but even a good design does not guarantee useful results (Field, 2011). Different types of questionnaires, such as posted and internet questionnaires exhibit different strength and disadvantages (Czaja and Blair, 2005, p. 35). Open ended questions are an option for discovery led research. However, the need for respondents to write their answers down is detrimental for their willingness to complete the questionnaire (Czaja and Blair, 2005). In any case, clear and unambiguous questions are a must (Sapsford, 2007, p. 111). In the field of PSS, in particular across different organisations such clarity in terminology is hard to achieve (Johnstone *et al.*, 2009).

4.3 Observation

Collecting information through observation require the researcher to record activities, using recording equipment, or by hand. Observation is a real time method for data collection (Blessing and Chakrabarti, 2009, p. 257). Cooke (1994, p. 805) discusses observation as an effective method to elicit knowledge from experts, for example strategies for problem solving. Observations can be made in a controlled or the natural environment and might involve active participation of the researcher. Similar to interviews, observations can be structured or focused (Cooke, 1994, p. 806). Other aspects of observation regard the participant's awareness of being observed, the duration of the observation and whether it is a one-of or recurring observation (Blessing and Chakrabarti, 2009). Denzin and Lincoln (2000, p. 634) argue that the observer cannot be detached from the setting under observation, and that the observer always plays an active role within the setting. One of the limitations of the observation method is that the behaviour or environment of interest might be inaccessible, be it for access restrictions, social norms or other reasons (Sapsford and Jupp, 2006, p. 59). In particular industrial

settings within the defence sector, the researcher's access and presence over a longer period of time can prove to be difficult.

4.4 Document analysis

Documents represent a very heterogeneous set of data sources, such as personal notes, governmental released reports, photographs or documentation from private firms. Sapsford and Jupp (2006) distinguish between primary and secondary sources, the former representing the original account and the latter being about the primary source.

In general, document analysis deals with information that was not specifically created for the researcher (Bryman, 2012, p. 542). Therefore, accessibility to documentation can greatly vary. Material that was intended for publication, such as websites or official reports may be easily accessible by the researcher, whereas information that might carry sensitive contents can be impossible to access (Denscombe, 2010, pp. 220–221). Criteria for the selection and importance given to documents comprise credibility, authenticity, meaning, representativeness (Denscombe, 2010, p. 222). Bryman (2012, p. 551) highlights that documents created in companies should not be taken as objective accounts of a situation and have to be considered carefully in relation to the context they have been produced in. Document analysis presents itself as a useful method for data collection to complement other sources, such as interviews or observations, as for example demonstrated by Börjesson (1994). For a researcher in an industrial setting there is a need to understand which type of information is available and accessible before selecting documents as a primary source of data.

4.5 Triangulation

A general definition of triangulation is the *“tracing and measurement of a series or network of triangles in order to survey and map out a territory or region”* (McCracken, 2012). It is for example applied as a method of navigation to determine one's current position by taking multiple bearings to significant points, such as a church tower or mountain summit. In research, triangulation means the application of multiple methods for data collection or analysis to describe the same phenomenon (Denscombe, 2010, p. 346). Denscombe (2010, p. 348) highlights that observations related to social phenomena should not literally be compared to observations of

locations in the physical world, such as a church tower. Rather, triangulation should be seen as a metaphor for looking at something from different perspectives. Atkinson and Coffey (2002) problematize the relationship between interviews and observation and conclude that the differences between actions as observed by the researcher and actions as reported by the participant need not be seen as different perspectives on the same thing, but represent observations in their own right. Furthermore, Atkinson and Coffey (2002, p. 812) strongly oppose uncritically favouring observation as “*what people do*” over interviews where “*people say what they do*”. Stake (2000, pp. 443–444) clarifies that through triangulation different meanings of the same phenomenon can be identified.

4.6 Ethical considerations

Research involving human subjects requires the researcher to deal with ethical codes and regulations (Warren, 2002, p. 88). One of the principles is that people participating in research should do so voluntarily and on an informed consent basis (Denscombe, 2010, p. 331). There is a general responsibility of the researcher to protect participants from harm they might suffer as a consequence of taking part in a study (Denscombe, 2010, p. 331). Sapsford and Jupp (2006, p. 297) extend the concept of ‘not causing harm’ to those who are not studied. In international business relations in aerospace for example one might raise the question whether optimising contractual agreements from the perspective of large OEMs might not harm small companies further down the supply chain (Velocci, Jr., 2014).

In particular in studies that rely on qualitative data from a relatively small number of interviews it is important to protect the identities of participants (Payne, 1999, p. 95). Denscombe (2010, pp. 344–345) outlines the following principles for data protection:

- Collect and process data in a fair and lawful manner;
- Use data only for the purposes originally specified;
- Collect only the data that are actually needed;
- Take care to ensure the data are accurate;
- Keep data no longer than is necessary;
- Keep the data secure;
- Not distribute the data;
- Restrict access to data;

- Keep data anonymous.

More detailed and comprehensive guidelines to ethics in socio-economical research are provided by Dench *et al.* (2004).

4.7 Methods for data collection described in the literature

The application of interviews is common practice in cost engineering as well as

Table 14 The use of interviews in the literature.

Purpose	Reference	Methodical details given
Process modelling (Stakeholder dialogue)	National Institute of Standards and Technology, 1993	<i>"The author personally interviews an expert on the subject matter"</i>
Maintenance cost modelling (Category definition & cost data)	Sinkkonen <i>et al.</i> , 2013	<i>"The data were collected with interviews in the chosen network companies, as well as in the form of quantitative and qualitative written company data."</i>
Activity-based-costing (ABC) (Cost data)	Lindholm and Suomala, 2007	<i>"Participation or observation (ca. 14 days) in the organization was needed for understanding the context and collecting part of the input data for cost modeling. Interviews and group interviews (n ¼ 12) were used both for collecting cost data and for reflecting the impacts of LCC [Life Cycle Costing] in the case organization."</i>
ABC (Flow charts)	Schulze <i>et al.</i> , 2012	Research process including multiple data collection techniques described; <i>"Semi-structured interviews (62 in total, of which 23 were conducted with staff member outside the facade components manufacturer): [details about job titles and company] [...]"</i>
PSS (Descriptive case study)	Johnstone <i>et al.</i> , 2009	<i>"A total of 18 interviews were conducted with key actors involved in devising and operationalising P-S strategy. These informants were carefully selected to represent a stratified cross-section of key managers with responsibility for the implementation of the strategy. The interviews were conducted in 2007, and typically lasted around 60 min, although several lasted up to 2 h. These allowed rich and detailed accounts of individual experiences and perceptions to be obtained. Interviews were semi-structured around themes including the espoused business strategy of JetCo, actor understanding of the notion of "[Product-Service]", the implications of enacting such strategies, and the associated challenges."</i>
Cost estimation of obsolescence (Cost data)	Romero Rojo <i>et al.</i> , 2012	<i>"The first phase aimed to gain an understanding of obsolescence and cost estimation through a literature review and semi-structured interviews with experts from industry."</i>

Table 14 (continued)

Purpose	Reference	Methodical details given
Enterprise imaging (Discussion & problem formulation)	Mills <i>et al.</i> , 2013	<i>"Interviews were semi-structured, face-to-face, and took an average of 1.5 h. [...] All interviews were recorded and transcribed and followed the ethical guidelines described by Maylor and Blackmon (2005). Thus, research subjects were informed fully about the purpose, methods, and intended uses of the research. Moreover, the confidentiality of the data was guaranteed and in line with these standards the interviewees participated voluntarily and free from coercion. 22 provider and six client interviews were undertaken."</i>
ABC (Identification of activities & cost drivers & allocation of expenditures to cost drivers)	Börjesson, 1994	<i>"Data on the two cases was obtained by personal interviews, complemented by documents about the systems."</i>
LCC and life cycle assessment (Cost and process data)	Lindahl <i>et al.</i> , 2014	<i>"Literature studies, semi-structured interviews and questionnaires with the company staffs were the methods used for gathering data about the cases. [...] Strong trust between the authors and participating companies, built over many years, has enabled unique access to data that are considered to be business secrets in many companies. These data have been carefully managed and agglomerated so that the final results do not reveal sensitive secrets, yet maintain the sufficient sources for scientific argumentation."</i>
Cost estimation (Unclear, example shows an equation for a manufacturing process)	Sandberg <i>et al.</i> , 2005	<i>"Knowledge acquisition was performed through formal and informal interviews with the industrial partner and by reading company reports."</i>
Maintenance and repair cost modelling (Parameters of Weibull distribution)	Waghmode and Sahasrabudhe, 2011	<i>"The values of [the Weibull lifetime distribution] for the different pump components [...] are obtained from the pump manufacturer based on the expert judgements."</i>

process modelling in general and PSS modelling in particular, see Table 14 for examples. However, as shown in the third column the details given about the interview process are often kept to a minimum. Furthermore, none of the examples in Table 14 discusses challenges experienced during the interviewing process.

To this regard, there is a distinction to be made between studies that use qualitative data from interviews to frame a problem, e.g. to support stakeholder

dialogue, and those that provide an answer to an already specified problem, e.g. to collect cost data. The first column in Table 15 shows that most studies concerned with cost estimation seek specific data through interviews. An exception is the paper by Schulze *et al.* (2012) who use interviews to construct a process chain for a quantitative ABC model. Still, their process model is shaped by the quantities of interest and while qualitative insights are incorporated it is a quantitative model that is created.

The way interviews are mentioned in several references (Börjesson, 1994; Romero Rojo *et al.*, 2012; Sinkkonen *et al.*, 2013; National Institute of Standards and Technology, 1993) suggests that how interviews were conducted and planned needs no further consideration, thus interviews seem to be considered common sense. Harrington (2005, p. 6) explains the *"difference between social theory and common sense is that social theory seeks to systematize and clarify debate about goals and problems of social life through well-defined concepts and techniques of analysis."* By shading some light on these problematic methodological aspects often overlooked in the literature, this work contributes to the debate through a clarification of the methodological consequences when dealing with PSS as socio-technical systems.

The use of multiple methods for data collection is mentioned in several references. There is however a great variety in the details provided about each method and how different methods are combined. Datta and Roy (2010, p. 150) for example show and describe how workshops among experts and interviews were combined. Schulze *et al.* (2012, p. 721) provide a list with the methods employed for data collection, namely one-to-one interviews (see also Table 14), company internal documentation and observation.

Ethical considerations are mentioned in the literature, however not frequently. For example Mills *et al.* (2013) (see Table 14) specify the ethical guideline followed in the research including confidentiality and participant information. Lindahl *et al.* (2014) point out the importance of trust between the researcher and the industrial participants for gaining access to sensitive information and how to handle with such information.

4.8 Selected methods

To understand *how* availability is delivered, eliciting knowledge from people involved in the on-going activities is considered appropriate. As a suitable method for describing what the PSS (the unit of analysis) constitutes from the perspective of people involved in delivering the desired outcome (the units of measurement) semi-structured interviews were selected (Blessing and Chakrabarti, 2009). In a similar context semi-structured interviews have been applied by Johnstone *et al.*, 2009 and Börjesson, 1994. The most significant advantage that interviews have over observation is that significantly less access to the case setting is required which reduces the risk of failing to collect relevant data. Furthermore, upfront planning of the effort and time required by collaborators from industry is facilitated.

Open ended questionnaires are not considered suitable for the given context due to unfamiliarity of the researcher with company-specific jargon. Also, it is expected that practitioners in industry are less comfortable with writing potentially lengthy answers than with expressing their views in a one-to-one situation. In addition to interviews, documentation provided by collaborating companies can be used for clarification and for establishing links between insights gained through interviews.

5 Methods for data analysis

In general 'analysis' refers to the process or the result of the process of a detailed examination, interpretation or formulation of essential features of something (McCracken, 2012). Thus, analysis is a way of understanding and making sense of the data concerning the phenomenon under investigation.

The data created through interviews is usually translated into text form, either as notes or transcripts from audio or video recordings. The direct analysis of audio and video records, for example by means of frequency analysis software, is not further discussed here.

An important aspect of the data analysis is whether the researcher is interested in "the nature of something", i.e. the qualities of a phenomenon, or quantifiable properties of the phenomenon (Åsberg *et al.*, 2011, p. 411). This aspect is particularly highlighted by Åsberg *et al.* (2011), who argue that it is the data itself

that carries the quantitative qualitative distinction. As shown in Table 14, interviews can be employed to collect quantities, for example cost figures (Romero Rojo *et al.*, 2012) and product reliability parameters (Waghmode and Sahasrabudhe, 2011), as well as qualitative insights such as the implementation of business strategies (Johnstone *et al.*, 2009). However, it is not only the type of data that determines whether quantitative or qualitative insights are gained, but also the type of analysis. If textual data is gathered through interviews it can be analysed according to its quantities, for example word counts, or relating to its meaning. Therefore, as framed above it is the interest of the researcher that determines which meaning is derived from the data, and how meaning is derived from the data.

The following two sections give an overview of methods for text analysis producing quantitative and qualitative insights. Section 5.3 discusses the use of models for gaining insight into the characteristics of the phenomenon under investigation.

5.1 *Quantitative analysis*

Content analysis, as described by Denscombe (2010, pp. 281–283) is a way of quantifying text, be it in the form of pictures, writing or sounds. Content analysis follows a process of breaking the selected data down into units of analysis, for example single words in a text, and assigning these units to specified categories by coding the data. Bryman (2012, pp. 298–304) outlines the use of schedules and manuals for coding the data. Subsequently the frequency of categories assigned to the data is determined. Further analysis can explore the relationships between different categories.

One of the strengths of content analysis lies in its direct link between the data and the results. The researcher is not asked to interpret the meaning that someone ‘could’ have implied. At the same time, this approach has a tendency to dislocate the units of analysis from their context in the data and thereby removes meaning that is linked to the context. Therefore, content analysis is less suitable for identifying subtle meanings or schemes that need to be inferred by the analyst (Denscombe, 2010, pp. 282–283). Additionally, terminological ambiguity arises where, depending on the context, one word has different meanings can render the results of content analysis questionable.

5.2 *Qualitative analysis*

The qualitative analysis of qualitative data (as opposed to the quantification of qualitative data) – here mainly referring to written text, such as transcripts from interview recordings – aims to reveal underlying structures, implications and interpretations within the data (Denscombe, 2010, p. 280). As content analysis, qualitative analysis relies on the process of coding the text. Codes can be predefined or emerge through the analysis. Thus, the coding scheme, i.e. the categories of analysis can be either developed before starting the analysis, for example derived from the literature or a theory to be tested, or categories can evolve as the analysis progresses. Also a combination of both is possible (Blessing and Chakrabarti, 2009, pp. 116–117). In qualitative analysis codes can be used as “*tags*” applied to any useful length of text, or “*values*” associated to specific units of analysis, as for example single words or person. While tags can overlap, values cannot, meaning one piece of text can only be assigned one particular value (Ryan and Bernard, 2000, p. 782).

5.2.1 Grounded theory

Grounded theory, a research strategy, involves a particular process of data analysis involving inductive coding and category development, outlined for example by Bartlett and Payne (1997) and Bryman (2012, pp. 567–575). The generation of categories from the data is followed by the saturation of these categories; that is when no new examples of these categories within the data can be identified. For each of the categories a formal definition is created to describe the category’s properties and dimensions. These definitions are then tested and further developed in theoretically chosen samples from additional data. Relationships between categories are established through further sampling and coding. Categories are then hierarchically ordered and linked to one core category that is linked to existing theories. Finally, the developed theory is tested (grounded) against the data and potential gaps are filled by collecting further relevant data (Bartlett and Payne, 1997). Data analysis strictly following the grounded theory approach can be very time consuming considering the continuing and overlapping activities of data collection and data analysis (Bryman, 2012, p. 574). In a context where access to data and participants is uncertain grounded theory is probably not an approach for data analysis that can be followed rigorously.

5.2.2 Thematic analysis

Thematic analysis is “*only*” a method for qualitative data analysis, not a research strategy, as for example grounded theory. As such, it is suitable for different types of research and theoretical perspectives (Braun and Clarke, 2012, p. 58). According to Bryman (2012), thematic analysis, although not as clearly defined an approach as for example grounded theory or discourse analysis, yet, is an approach frequently quoted in the literature. Braun and Clarke (2012, pp. 60–69) introduce a five phases description of how to conduct thematic analysis.

- Phase 1: Familiarisation with the data
The researcher should “immerse” himself into the data to become intimately familiar with the data. The process includes reading, listening, taking notes and asking critical questions. Transcribing audio or video recordings is a recommended way of familiarisation.
- Phase 2: Generation of initial codes
In this phase codes are generated from the data, or existing codes are assigned to the data (Fereday and Miur-Cochrane, 2006). There can be any number of codes, and they need not be organised or sorted.
- Phase 3: Searching for themes
Themes are constructed by the researcher to arrange codes, through the identification of overlaps and relationships between codes. During this phase also relationships between themes are explored to understand how themes and sub-themes are linked. This stage can lead to consolidating codes that may not fit into themes and might be discarded.
- Phase 4: Review of potential themes
Evaluating the themes in terms of their meaningfulness, boundaries and internal coherence is part of the review of themes. It might involve discarding themes, regrouping codes or merging themes. Part of the review process is to determine how the themes relate to the overall dataset and whether they capture the ‘tone’ of entirety of the data.
- Phase 5: Definition and naming of themes
Each theme should be named and characterised in terms of scope and purpose, in particular how it related to the research question. To illustrate the essence of each theme, direct quotations can be used.

- Phase 6: Produce report

Reporting the results of the analysis should present the themes, how they are connected and how they relate to the overall data.

Depending on how the analysis is carried out, thematic analysis can provide descriptive results that illustrate a phenomenon, or more interpretive results that reveal latent meanings or underlying structures. Both approaches to the analysis can also be combined to provide a more interpretive description of the phenomenon. However, the latter is more difficult and requires experience by the researcher (Braun and Clarke, 2012, p. 67). In general, thematic analysis is a flexible method suitable for inductive and deductive approaches as well as a combination of both.

5.2.3 Discourse analysis

Discourse is defined as *“instances of structured regulated communication through spoken or written language and other systems of symbolic inscription or representation”* (Harrington, 2005, p. 319). One of the premises of discourse analysis is that words are not simply used to represent a reality but rather words are used as a way of creating and sustaining reality (Denscombe, 2010, p. 287). Discourse analysis aims to disclose the underlying goals people want to achieve through talk, and the conditions needed for these goals to be achieved. In an organisational context discourse analysis can be used to address questions such as:

“What are the conditions that enable certain statements to be articulated (spoken or written) and to survive within an organization while others are smothered or never articulated?” (Topp, 2000, p. 366)

Andersen (2003) examines approaches from Foucault, Koselleck, Laclau and Luhmann, and suggests analytical strategies for understanding sociological phenomena.

Discourse analysis requires close scrutiny of the text under investigation and leads to conclusions grounded in the data, similar to the other methods of data analysis described above. A significant difference is that the discourse analysis relies on theories and assumptions that were developed separately from the data (Denscombe, 2010, p. 288). In particular knowledge about theoretical perspectives

on language is essential because this background guides the analysis and informs the conclusions that are drawn (Braun and Clarke, 2012, p. 58).

5.3 Models

An effective way of describing what models are, how they can be used and what needs to be known ‘to model’ is given by Peterson (1981, p. 1):

“A model is a representation, often in mathematical terms, of what are felt to be the important features of the object or system under study.

By manipulation of the representation, it is hoped that new knowledge about the modeled phenomena can be obtained [...] To successfully utilize the modeling approach, however, requires a knowledge of both the modeled phenomena and the properties of the modeling technique”.

The key elements outlined in that quote concern the specific interest in a phenomenon and its representation. Therefore, modelling requires knowledge about *how* to model, *what* to model and *why* to model.

In this research the ‘why’ is addressed in Part I, the Introduction – it is to support modelling the cost of availability provision through a PSS. Hereby, ‘what’ is defined as ‘the PSS delivering avionics availability’. By contrast, the *“important features”* of the phenomenon are not decided upfront, they are a result of this research. Modelling techniques, addressing ‘how’, are outlined below.

5.3.1 Is a model a small scale of the ‘real’ world?

There are two fundamentally opposing views on models: One view is that a model is a description of a *“way of thinking about the real world”* Wilson (2001, p. 4) and not the real world itself. Also Leontief stresses that a model is not *“a small-scale replica of the real thing”* (1986, p. 420). Such view is in stark contrast to Becker *et al.* (2010, p. 36) who define conceptual models as *“a (re-) construction of a reality”*. In a similar manner, Löfstrand *et al.* (2012, p. 308) claim their model elements *“mirroring the reality”* without however clarifying how knowledge about ‘reality’ shall be gained.

In this research Wilson’s perspective is adapted as it accounts for the characteristics of PSS as socio-technical systems consistently when taking a theoretical perspective of constructionism. Because the model does not reflect ‘the

reality', it is always constructed following a rational for a specific purpose. It means that a model that is "*adequate for one purpose does not imply that it is adequate for another purpose*" (Evans, 1995, p. 537). The purpose of a model, in the context of socio-technical systems is a determining factor for drawing the boundaries and deciding what shall be included and what shall not be included (Dekker, 2011, pp. 139–140).

At this point, the relationship between 'model' and 'system' needs clarification. Following Checkland and Scholes (1999, pp. A10), systems represent a way of thinking about the world. That is, when investigating the world for a particular purpose, the 'system' contains those elements and relationships that are relevant to the particular purpose. Through the identification of the 'relevant' elements and relationships the system boundaries are defined. A model, as quoted above, is a description of the world resulting from thinking about the world 'as system'.

However, without knowing the system, how can one draw the boundaries and decide what shall be included and what not? This question refers to "*the important features*" of the PSS this research seeks to identify by describing *how* availability is delivered.

Therefore, consistent with the Soft System Methodology (SSM), the purpose is to frame the problematic situation and the model is seen as an agreed representation and description of the phenomenon, here the PSS (Checkland and Scholes, 1999). Hence, a qualitative model that represents the relevant system elements is appropriate to address the need for a PSS description. While in SSM "Rich Pictures" are employed (Checkland and Scholes, 1999), other representation techniques might be employed to serve the same purpose.

5.3.2 Process models

Process maps represent a system as elements (processes) and the relationships between them, for example material or information flow. Process maps are useful for visualising *what* is done (Aguilar-Saven, 2004) and in particular function-oriented maps are useful to understand how a socio-technical system works (Hollnagel, 2012).

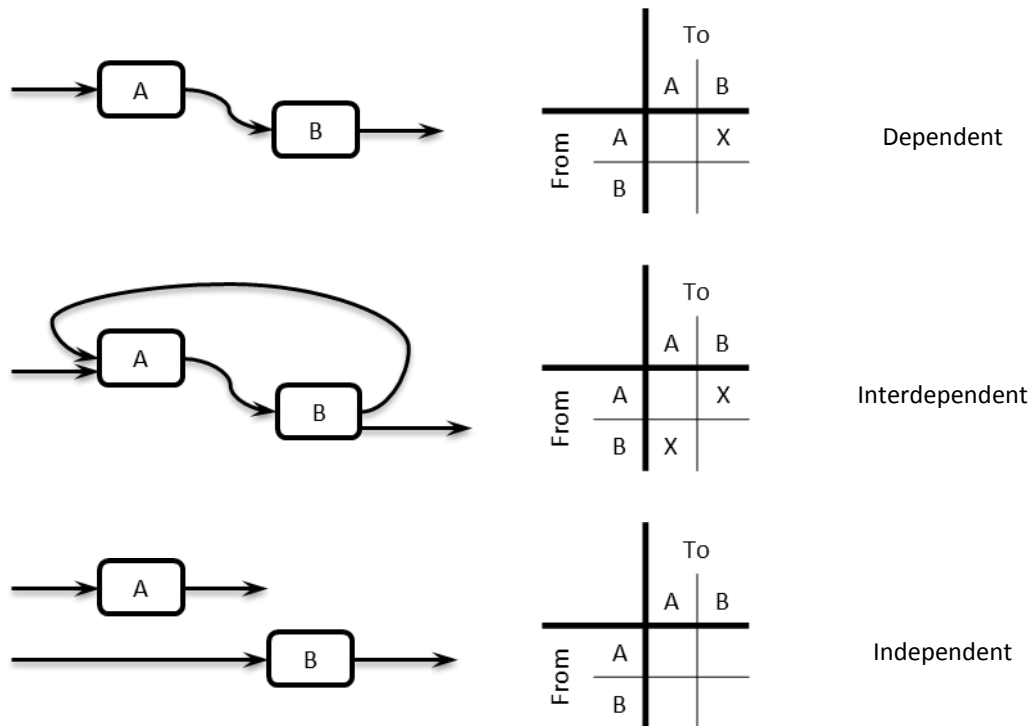


Figure 12 Relationships between the processes A and B, in diagrammatic (left) and matrix (middle) representation.

It is the aim of the CATA project to build a quantitative system model and cost model on the qualitative description of the PSS, i.e. the qualitative PSS model. Therefore, the qualitative model ideally supports a structure that can be translated into a quantitative model, for example through Petri Nets and/or matrix operations as demonstrated in the design of automated manufacturing systems by Santarek and Buseif (1998) and proposed for PSS delivering advanced services by Settanni *et al.* (2013). Using a notation similar to the Design Structure Matrix (Yang *et al.*, 2012) Figure 12 shows examples of diagrammatic and matrix representation of dependence, interdependence and independence relationships between processes.

To select an appropriate mapping method it is necessary to consider that the tool itself is not “*neutral*” and imposes a certain viewpoint by the way it represents the system under investigation (Biazzo, 2002). Ma *et al.* (2002) point out that the representation of a service would enhance a profound understanding of what a service operations system tries to convey to customers. Diagrammatic process models are identified as the most promising way of representing service delivery systems and their operation, and the strengths and weaknesses of several such

models are reviewed. Durugbo *et al.* (2011), review diagrammatic representation techniques of information flow in PSS and conclude that there is no single best method for the given purpose. They highlight the need for further research on the information flow through PSS, including the flow of information within a single company as well as across companies.

5.3.3 The IDEF0 standard

The IDEF0 standard describes the creation of maps “*comprising system functions (actions, processes, operations), functional relationships, and the data and objects that support systems [and] enterprise analysis*”, to “*facilitate understanding, communication, consensus and validation*” (National Institute of Standards and Technology, 1993, p. 13). IDEF0 support the representation of functions and relationships across organizational boundaries, incorporate resource as well as data, information and knowledge flow. While being well structured IDEF0 maps allow the user to designate the elements according to the specific context supporting the alignment of terminology and meaning across functions and groups. Additionally, IDEF0 maps allow for a representation of detail as required for the particular purpose, and the introduction greater detail once it unfolds. The creation of IDEF0 maps is described as an iterative process involving feedback loops between the author and a commenter (National Institute of Standards and Technology, 1993, p. 91). The hierarchical structure of an IDEF0 map allows for the gradual introduction of detail in IDEF0 according to the level of insight the researcher has gained. Such characteristic can facilitate focusing a discussion on the specific area of interest.

In their review of business process modelling techniques Aguilar-Saven (2004) identify the IDEF0 standard as advantageous for the modeller, allowing quick mapping while not having explicit weaknesses. Emblemssvåg (2003, p. 158) recommends this technique for the creation of detailed process maps for ABC. Specific applications of IDEF0 to support ABC include the estimation of design and development costs of mechanical parts (Ben-Arieh and Qian, 2003).

5.3.4 The FRAM

The Functional Resonance Analysis Method (FRAM) (Hollnagel, 2012) is an approach, to explain outcomes by interactions between multiple system elements, rather than direct cause and effect relations between two elements. It has been

developed for accident investigation and risk analysis. As such it is equipped to deal with socio-technical systems to provide insights into why and how they normally succeed and occasionally fail. One of its foundations is the assumption that success and failure exist for the same reasons. For service provision this viewpoint is highly valuable as the insights provided include the enabling conditions as well as threats for the delivery to be successful. It can capture phenomena across hierarchical levels, be they individual or organisational. Hence, it is suitable for use in identifying holistic phenomena of socio-technical systems (Hollnagel, 2012), such as command and control and fire fighting functions (Åhman, 2013; Woltjer, 2009).

5.4 Data analysis as described in the literature

In this section the methods for qualitative data analysis as well as approaches to the representation of PSS as described in the literature are discussed.

5.4.1 Qualitative data analysis

The use of qualitative data – as for example from interviews – is fairly common in the literature concerning PSS and cost engineering, as anticipated in section 4.7. However, details about how the analysis was carried out are relatively sparse, as shown in Table 15. In particular, none of the references names the method applied for coding the data.

In the field of cost engineering, the methodical insights about the analysis of interview data provided for example by Romero Rojo *et al.* (2012) is limited to the purpose of the interview. That is “*the identification of key factors and cost drivers for obsolescence, together with the type of information available at different stages of the life cycle of the system*” (Romero Rojo *et al.*, 2012, p. 157). Similarly, the process of the subsequent “*qualitative validation*” of a quantitative model with “*experts*” is not made transparent.

Also in the field of cost modelling, more details are given by Schulze *et al.* (2012) who use interviews to construct process diagrams a quantitative ABC model. They do however not report on transcribing the interview recordings into text. Accordingly, it appears that they do not analyse the interviews following any of the methods outlined in sections 5.2. By comparison, Mills *et al.* (2013) state that

Table 15 Data analysis in the literature.

Purpose	Reference	Qualitative data analysis
ABC (Flow charts)	Schulze <i>et al.</i> , 2012	<i>"Data Analysis: Process diagrams with transaction analysis: Data was transcribed in flow charts backed up with a detailed description of procedures, documents and data for each identified process/activity."</i>
Cost estimation of obsolescence (Cost data)	Romero Rojo <i>et al.</i> , 2012	<i>"An MS Excel-based prototype for the cost estimation of obsolescence was developed and iteratively enhanced, based on qualitative validation carried out in collaboration with experts from different organizations."</i>
Enterprise imaging (Discussion & problem formulation)	Mills <i>et al.</i> , 2013	<i>"All interviews were recorded and transcribed [...]"</i> Details about the analysis of the transcripts are not provided. It is however stated that the maps were updated and discussed during the interview process.
Description of Product-Service business implementation	Johnstone <i>et al.</i> , 2009	<i>"All interviews were recorded, transcribed verbatim and subsequently coded, using both categories which reflected the research questions which informed the interview template [...], as well as new categories which emerged from the data [...]. As such, the analytical framework was both deductively and inductively derived; the major headings and areas of exploration were derived from a fairly structured template, but the specific issues faced in operationalising P-S [Product Service] strategy were largely emergent."</i>

the interview recordings were transcribed, but they do not provide details about how the analysis of the transcripts contributed to the creation of the enterprise image, a representation of the research context. Significantly more detail is given by Johnstone *et al.* (2009) who report on coding interview transcripts using inductive and deductive categories. The codes, themes or relationships among them are however not visualised, as for example suggested by Ryan and Bernard (2000, p. 784). Instead, the findings are presented by means of example quotes.

5.4.2 Qualitative models of PSS delivering availability

While there is a significant number of publications concerned with the modelling of service and PSS for design purposes, see for example (Kim *et al.*, 2011b; Becker *et al.*, 2010; Aurich *et al.*, 2006; Alonso-Rasgado *et al.*, 2004; Ma *et al.*, 2002), the articles on how advanced services are actually delivered are much more scarce. Despite the importance of other factors for successful PSS implementation than a sound design method (Tukker, 2013) the only example concerning the modelling

of an existing PSS delivering advanced services that could be identified is the enterprise image proposed by Mills *et al.* (2013).

Based on extensive analysis of the existing literature, Phumbua and Tjahjono (2012) recognise a need for case study research in PSS modelling. Durugbo *et al.* (2011), conclude that diagrammatic models to represent information flows show an incomplete picture of PSS. They propose that empirical studies take a wider perspective and take business processes and organisational structure into account. At the same time, Cavalieri and Pezzotta (2012) highlight the limited availability of tools for PSS modelling in working context.

Nevertheless, models should not be identified with specific software used to outline them; rather with the modelling technique employed, such as those reviewed by Aguilar-Saven (2004). Process modelling techniques which require not more than a pen and paper to draw a representation of the situation under investigation can be beneficial for modelling that supports and summarizes qualitative data analysis by showing relationships between elements, such as constructs or themes (Ryan and Bernard, 2000). A crucial aspect is that qualitative models, such as conceptual models are means of communication (Ryan and Bernard, 2000), in PSS for example within interdisciplinary project teams or other stakeholders such as project managers (Becker *et al.*, 2010).

To support the design of PSS Evans *et al.* (2007) conduct multiple exploratory case studies and show maps of different solutions for providing services. In aerospace Zhu *et al.* (2012) propose an IT-based PSS to integrate the aircraft development process with Maintenance, Repair and Overhaul (MRO) services. They use a high-level IDEF0 to represent generic MRO processes that are then formalised through more advanced IT solutions which are beyond the scope of this work. Accordingly, the case study Zhu *et al.* (2012) describe refers to software development and integration and not to the processes of a specific existing context in which MRO services are provided.

In the field of service operations Sampson (2012) suggests employing Process Chain Network (PCN) analysis to visualise activities across organisations. However, as noted by Mills *et al.* (2013) with regards to service blueprinting, the focus of PCN is a single process (comprised of several activities). Also, PCN applications seem to focus on consumer services, as for example in a pizza

restaurant, not on advanced services like availability. Also consumer service related, Maull *et al.* (2013) illustrate a PSS supply chain using the IDEF0 standard (National Institute of Standards and Technology, 1993).

In an industrial business to business context Meier *et al.* (2010b, p. 166) show a generic descriptive model of organisations contributing to the delivery of an Industrial PSS. Being more specific and based on an exploratory case study Lockett *et al.* (2011) discuss the relationships between three companies delivering a combined package of product including maintenance, monitoring and repair services. It is however unclear how critical these deliverables are for the customer's core business processes, as would be the case for an advanced service. Additionally, the representation of the PSS they provide is a high level overview of the organisations involved and the links between them with no specifics *how* the outcome is delivered.

A specific case of availability provision for ships is explored by Houghton and Lea (2009). The authors focus mainly on technical hierarchies as well as organisational functions required to maintain operational readiness. Despite showing a number of diagrammatic representations, these lack a network structure. Furthermore, availability as a performance metric is described as resulting from specific parameters such as Mean Time To Repair (MTTR) and MTBF rather than a network of interlinked activities within the PSS.

Similarly, Mills *et al.* (2013) who provide an academic case study of availability provision in aerospace are not concerned with the network of activities. Rather, their model, an enterprise image, shows key actors of a multi-organisational enterprise that is intended to "*provide a common reference point for multiple interpretations; form a basis for co-creating holistic enterprise management processes.*" (Mills *et al.*, 2013, p. 176). Such aim is in line with the argument made in this work that a problem needs to be formulated in a *defensible* and agreed representation *before* it can be solved. However, it lacks the relationships between the constituting elements and therefore does not qualify as a *system* model.

Investigating availability contracts in the defence sector through two exploratory case studies, Datta and Roy (2011) provide a high level conceptual strategy framework for performance based contract operations. Their article entails a "*Service delivery framework*" created by one of the companies involved in the study.

Table 16 Models of PSS for design and operations purposes.

	Design	Operations
Consumer service	Kim <i>et al.</i> , 2011b Evans <i>et al.</i> , 2007*	Sampson, 2012 Maull <i>et al.</i> , 2013
Industrial context	Alonso-Rasgado <i>et al.</i> , 2004 Aurich <i>et al.</i> , 2006 Evans <i>et al.</i> , 2007* Meier <i>et al.</i> , 2010b	Houghton and Lea, 2009 Datta and Roy, 2011 Lockett <i>et al.</i> , 2011 Mills <i>et al.</i> , 2013
* Evans <i>et al.</i> conduct multiple case studies that cover consumer service as well as the industrial context.		

This representation puts emphasis on the accountability of the specific company in the context of different locations, functions and organisational entities. It remains unclear whether the shown entities represent organisational units such as groups or departments, or stand for functions that might be distributed across organisational units. Furthermore, the flow of information and equipment is unspecific. Overall, the insights into *how* the multiple organisations involved deliver the service is limited to high level entities and generic relationships.

Table 16 summarises how examples of the literature can be categorised according to the purpose of modelling and the context the PSS operates in. The latter is distinguished by the proximity to the individual end consumer. While ‘consumer service’ directly targets the individual, the ‘industrial context’ is characterised by relationships among organisations. It should be noted that not all PSS operating in an industrial context provide ‘advanced services’, such as availability.

5.4.3 Representation of PSS in cost estimation

When it comes to cost modelling for PSS Settanni *et al.* conclude the scope of such models tends “*to be determined as the time-span a product unit exists, rather than the actions performed within the enterprise, their outcomes, relationships and occurrence.* (2014, p. 13).” However, the sheer existence of a conceptual representation of a delivery system does not necessarily mean that this affects the computation of costs. An example is Komoto and Tomiyama (2008) who show a conceptual model of a PSS, nonetheless, the simulation of life cycle costs follows on a common product-centred reliability engineering-based line. Typically such approach identifies service with a repair event that is a direct result of a product failing. The

costs of service are then determined by the number of product failures and the average costs for a repair, see for example Sandborn (2013).

Most examples of approaches that ground the determination of cost on an explicit representation of a network of activities are based on ABC (Schulze *et al.*, 2012; Ben-Arieh and Qian, 2003; Emblemståg, 2003; Mirghani, 1996), or Material and Energy Flow-based Accounting (Möller, 2010). However, none of these studies is concerned with availability being delivered by a PSS. The simulation of service costs building on a combination of ABC and service blueprinting is proposed by Kimita *et al.* (2012) and Kimita *et al.* (2009). Due to the service design purpose of their approach upfront decisions on cost drivers and assignment of quantities to specific activities can be made. Compared to models based on case study research these system characteristics do not need to be derived from empirical data. Börjesson (1994) specifically highlight the importance of qualitative activity information extracted from empirical data for ABC, in particular for the implementation of process improvements.

5.5 *Selected methods*

The first selection concerns whether the researcher's interest in the data can be fulfilled through quantitative or qualitative analysis of interview recordings, or more specific, the transcripts of interview recordings.

In this research, the focus is on the identification of the elements relevant to the delivery of avionics availability through a PSS. If terminology in all organisations would be aligned, i.e. the meaning of an expression was the same everywhere; content analysis could provide insights about the relevance of specific concepts. These could be activities, types of information, material or characteristics of the product. However, such assumption cannot be made. Therefore, it is necessary to understand meaning before one can determine if terminology as aligned. Consequently, a qualitative data analysis approach is chosen. Of those three introduced above, thematic analysis seems to be most appropriate. The grounded theory approach requires an extended interplay between data collection and analysis which can pose significant challenges in a time-restricted project and potentially access restricted context. On the other side, discourse analysis requires extensive theoretical analysis about the use of language upfront. In the given context and domain such foundation cannot be provided. Furthermore, the

selected descriptive and inductive research type is not an immediate fit to grounded theory-led data analysis. All in all, thematic analysis is considered appropriate due to its flexibility allowing inductive as well as deductive coding and its strength in discovering themes from the data.

As seen in the discussion about data collection and data analysis methods, representations of models, can be effectively combined with interviews during the data collection phase (Mills *et al.*, 2013). In other contexts Hoffman *et al.* (1995) and Snyder *et al.* (1992) employ process maps to support data collection. The advantage of combining interviews with process maps is that visualisation, as described in Part I, section 2 can create a common understanding of a situation. In a context where terminological ambiguities can be expected supplementing interviews with process maps is seen as particularly useful.

For the selection of a suitable mapping technique, flexibility and the ability to facilitate communication between the researcher and the interviewee are among the most important requirements. IDEF0 maps can support these criteria. Their hierarchical structure is considered beneficial for focusing the discussion on the area of expertise of the respective interviewee.

6 Criteria for research quality

Research quality is a topic that offers a wide ranging debate, for example in the field of international business research (Andersen and Skaates, 2004). A terminological divide is evident when it comes to the distinction between research that openly discusses and acknowledges the role of the researcher on one side, and approaches that attempt to discover or describe ‘the world as it is’ on the other side. The latter reflects theoretical perspective of positivism. For example, Crotty (1998, p. 41) expresses strong concern about the use of quantitative data analysis for the ‘validation’ of insights derived from qualitative analysis, using attributes such as validity, objectivity and generalizability. Indeed, these three terms, in addition to ‘reliability’ are outlined by Denscombe (2010, p. 298) as conventional criteria to judge the credibility of research based on qualitative data analysis. Specifically aimed at case studies using a positivistic theoretical perspective, the criteria Gibbert *et al.* (2008, p. 1466) cited are construct validity, internal validity, external validity and reliability. Hereby, construct validity refers to the accurate observation of reality, internal validity to the causality between variables and

results, external validity to the validity of the findings in other contexts than the one being studied, and reliability refers to the replicability of the study.

Lützhöft *et al.* (2010, pp. 537–542) propose an adaption of these concepts to suit the characteristics of research in the human factors domain that does not follow the positivistic stance. Similarly, Denscombe (2010, pp. 299–302) illustrates how “conventional” criteria for research quality can be interpreted (and renamed) to suit the views of constructivist researchers. These are:

- Credibility: (internal) validity
Credibility says something about the suitability of the data for the given purpose. Ways to address issues of credibility include (careful) triangulation, checking of findings with participants, and grounding the findings closely to the data.
- Transferability (called “*generalizability*” by Denscombe, 2010): external validity
Using a small number of cases, or as is done in this research, a single case makes it difficult to claim that findings *can* be transferred into other contexts. Instead it is asked whether the findings “*could*” apply in other settings (Denscombe, 2010, p. 301). Lützhöft *et al.* (2010, p. 539) stipulate that it should be clearly specified *what* shall be generalised (or transferred) to other settings.
- Dependability: reliability
Dependability relates to the transparency of the research process, including the methods employed for data collection and analysis. It allows others, not necessarily to *replicate* the findings, but to follow the research process and how conclusions were drawn and why the study was undertaken in this way.
- Confirmability: objectivity
Research is never free from the researcher’s influence. The data collected through interviews is not just ‘out there’ to be discovered; rather, it is constructed in the specific circumstances between the researcher and the participant (Ryen, 2002, pp. 347–348). Consequently, confirmability relates to the researcher’s self and the way he or she interprets the data.

How the criteria for research quality were considered in the case study is outlined in Part IV, section 2.2. The following section provides a further discussion on the researcher and his role as well as aspects of the environment in research.

7 Positioning of the researcher / Values

The researcher, as an observer with a particular interest plays an active role in the research process, as highlighted by Dekker (2011, p. 140):

"We ourselves play a very active role in creating the world we observe, precisely because of our observations. If we don't have the language or the knowledge to see something, we won't see it. What our observations come up with is in large part up to us, the observers. [...] Human observation cannot be a neutral arbiter or producer of knowledge. After all, the observers themselves impose a particular language, interest, and they come with imaginations and a background that actively bring certain aspects of a problem into view, while leaving others obscured and unexamined."

Therefore, the researcher shapes how the research is conducted, what is searched for, and in the end, what can be found. After all, the researcher takes part in social process, contributes to their shaping and thus actively changes the world he or she analyses (Moses and Knutsen, 2007, p. 185).

Personal values and political interests are normally not discussed in engineering research. Nevertheless, they can play an important role for example in the military-industrial-academic complex (Blue *et al.*, 2014). Also cost estimations under budget constraints and professional pressures have a political aspect to them that might lead decision makers to ignore or manipulate estimates (Assidmi *et al.*, 2012, p. 1).

Funding of research – through industrial and military organisations in particular – requires the researcher to be aware of the own motivations and of the motivations of the funding bodies (Cheek, 2000, p. 418). Not only research funded through the participating organisations is prone to potential migration of interests from the industrial partner to the researcher. Macdonald and Hellgren (2004) discuss issues related to research in international organisations. They point out that getting and sustaining access to the organisation involves dynamics the researcher may not be

aware of, and that can affect the way interviews are conducted as well as what can be found.

The political dimension of research in knowledge management is discussed by Schultze and Stabell (2004, pp. 554–555) who contrast “*consensus*” and “*dissensus*” assumptions about the social order. Consensus-based assumptions consider trust and common interest underlying social relations, and take science and knowledge as neutral and free of political interest. By contrast, a social order based on dissensus comprises conflicts of interest and suspicion. Additionally, knowledge is seen as political and can be used by those in power to dominate or to emancipate those who are underprivileged. While this research does not take a ‘dissensus’ standpoint, the existence of power, conflict of interests and suspicion is not denied, allowing the discovery of themes relating to such phenomena.

A discussion of the researcher as a research tool can be found in Part V, section 4.6. More general reflections on the overall research process are presented in Part VI, section 4.

8 Summary of research methodology

The methodology outlined in this part comprises the theoretical perspective, research type and strategy, and methods for data collection and analysis. The selections made in this research are summarised in Figure 13. It is shown that the research undertaken is a descriptive case study taking a constructivist viewpoint and using qualitative data. Additionally, criteria for research relying on qualitative data analysis were discussed, and the importance of a transparent

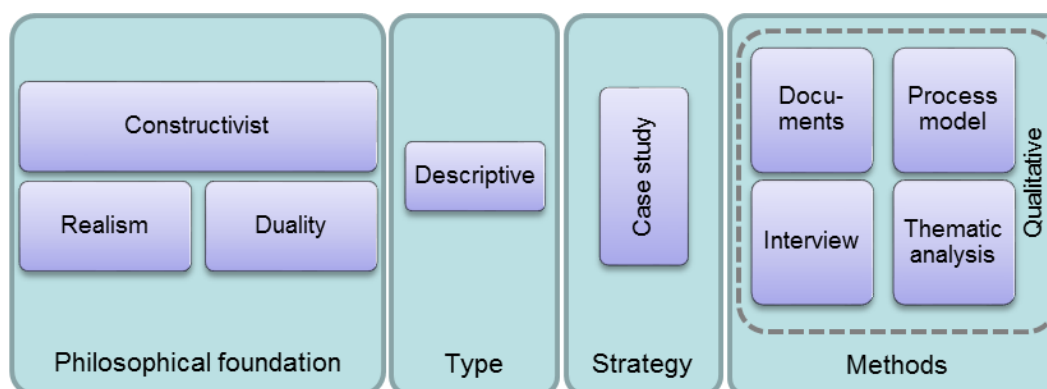


Figure 13 Research methodology as selected.

description of the research context, including the researcher was highlighted. *How* the methodological selection and quality demands are translated in the empirical study is presented in Part IV.

From the review of the literature it emerged that there is a limited number of studies investigating PSS which describe their methodology in detail and employ a methodology as selected in this research. Application and methods-wise the case study conducted by Mills *et al.* (2013) shows the highest degree of similarity to this work. Significantly, the difference between both is the purpose, the representation of a multi-organisation enterprise to support discussion in the case of Mills *et al.*, and a system model to support quantitative cost modelling in this work.

9 Concluding remarks

The phenomenon under investigation, an operative PSS, is interpreted as a socio-technical system. This view implies that a PSS can no longer be seen as a single tangible, indisputable object (Vermaas *et al.*, 2011). Also, it confronts those involved in the delivery of an advanced service through a PSS, as well as researchers with aspects that may not be captured by the methods employed in engineering, that are oriented towards the natural sciences (Vermaas *et al.*, 2011, p. 80). The same authors observe that it is engineers, employing engineering methods that are concerned with the design and operation of these socio-technical systems. Approaches to system engineering, such as the Multi Domain Matrix (Bartolomei *et al.*, 2012; Luft *et al.*, 2013), treat social and technical phenomena equally, and hence may be considered an evidence for this observation. The research presented in this work adapts a view on a *system* not as a given and existing entity, but as a way of thinking about and structuring the phenomenon, in this research the PSS (Checkland and Scholes, 1999).

Table 9 at the beginning of this chapter shows the principles of explanation for different objects. It reflects calls for the inclusion of insights and methods from the social sciences, accounting for the coexistence of humans and technical objects within socio-technical systems in general (Vermaas *et al.*, 2011), and PSS in particular (Mont and Tukker, 2006). Such viewpoint is shared by Boyer and Swink (2008) in the field of Operations and Supply Chain Management (OSCM) who argue that “*OSCM is a social science*”. They encourage the application of multiple approaches to achieve better understanding of the phenomena in OSCM. At the

same time they are concerned about “*a tendency in the academic community to discount the findings of others who are using their different ‘senses’ (research methods)*” (Boyer and Swink, 2008, p. 339). This research attempts to overcome such tendencies through the justification of selection of methods that is provided in this part. This outlined methodology underlies the empirical study that is described in the following part.

PART IV: EMPIRICAL STUDY

*I've done the math enough to know the dangers of our second guessing.
Doomed to crumble unless we grow, and strengthen our communication.*

Tool (2001)

As highlighted in the previous chapters, PSS are socio-technical systems (Morelli, 2002) and in such a context the very formulation of a problem is challenging (Wilson, 2001). Ill-defined problems are not uncommon in the engineering domain as demonstrated in the following by a historical example. This example shows how through a combination of methods the problem of the specification of design requirements for flying qualities was *formulated first* and then systematically solved. As described by Vincenti (1990, pp. 51–108), before the 1940s aircraft engineering designers did not know what flying qualities were needed by pilots or how they could be specified. So the question was “what are flying qualities?” and “how can one know about flying qualities?” Only when they were *described* could flying qualities be translated into quantifiable design specifications. Significant research undertaken to this purpose was characterised by its *qualitative* data analysis. The research involved the judgement of pilots that needed *interpretation* by the flight research engineers to derive *meaning* about the technical characteristics of the airplane. This process led to the identification and development of suitable means for measuring and quantifying the relevant properties of a pilot-controlled airplane (a socio-technical system) (Gilruth, 1943).

While the earliest formulations of flying qualities were written in similar terms as performance specifications (such as speed, weight, altitude), they were of no practical value in terms of how to translate them into an actual design. Only through a “*conceptually, analytically and experimentally complex*” process spanning over a quarter of a decade were practical specifications for flying qualities brought into being (Vincenti, 1990, p. 104).

Another example of engineers engaging in gathering insights from the social environment, is the work by Waddington and his colleges, described by Ignizio (2010, p. 18):

“... Waddington and his team had the audacity to stop and think. They requested and analyzed the supporting data, talked with maintenance crews, and took time to carefully and personally observe actual maintenance events (a decision quite unlike that of too many “analysts” who prefer to remain in their warm and comfortable offices, poring over and processing data provided from “the outside”).”

These examples demonstrates that an ill-defined problem requires understanding through a qualitative description of the phenomenon that precedes and continuously supports the development of *relevant quantification* (Wolstenholme, 1999). The need for a combination of qualitative and quantitative analysis has long been recognised in the engineering field. For example Novick (1966, pp. 9–10) points out that problems of a qualitative nature, that is, problems for which we do not have numbers, are just as important as, if not more important than quantitative considerations. In particular, he stresses that it would be incorrect to think that in the absence of quantifications an analysis is not possible, rather, analysing qualitative problems is an essential ingredient underpinning most quantitative works.

However, as seen in the previous Parts of this work, quantification has always been the focal point of cost engineering, leaving significant methodological gaps when it comes to handling qualitative data. In addition, to the relevance of ‘qualitative’ insights, the examples above show the relevance of evidence from the ‘real’ world. Such empirical evidence is opposed to theoretical evidence which is purely analytical or abstract (McNeill, 1990, pp. 1–2).

This part of the work contributes to the field of cost engineering with an empirical study that relies on the collection and analysis of qualitative data to provide a descriptive account of an operative PSS in the defence aerospace sector. The empirical study started in July 2011 and data collection ended in March 2014.

1 Case study setting

Figure 14 shows that the case investigated is predominantly centred around two organisations, the provider of aircraft availability (BAE Systems) and one of its main suppliers (GE Aviation). The boundaries of those two organisations are occasionally crossed, e.g. when it comes to the actual provision of availability which takes place on the user's airbase. This is where "*value in use*" is "co-created" (Parry *et al.*, 2011b, p. 67) by personnel working for BAE Systems together with personnel working for the RAF.

The study is based on an exemplary piece of avionics equipment, the Multi-functional Head Down Display (MHDD) which is installed in the Eurofighter Typhoon aircraft and supplied and supported by GE Aviation among other equipment. There are three MHDDs per single seat aircraft, which is the vast majority of all aircraft delivered, and six MHDDs in the twin seat version (Jackson, 2010). The contractual partner of BAE Systems is the UK MoD who purchase the aircraft and the means to support the aircraft.

While the empirical study was conducted, BAE Systems was under a fixed-price

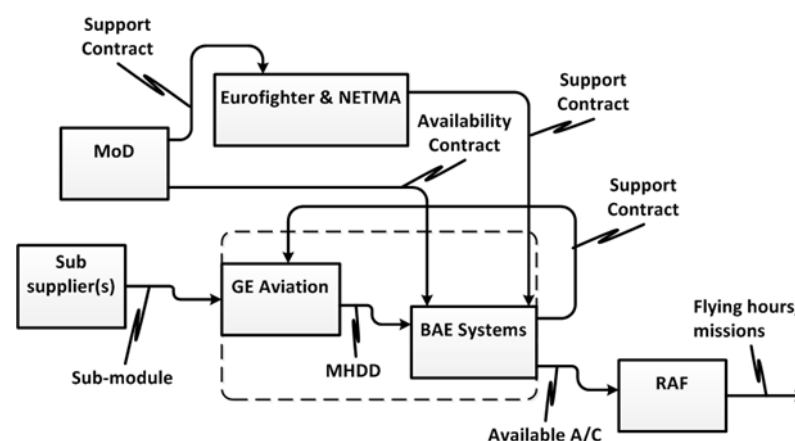


Figure 14 Organisations involved in the case setting; unit of analysis lies within the dashed box.

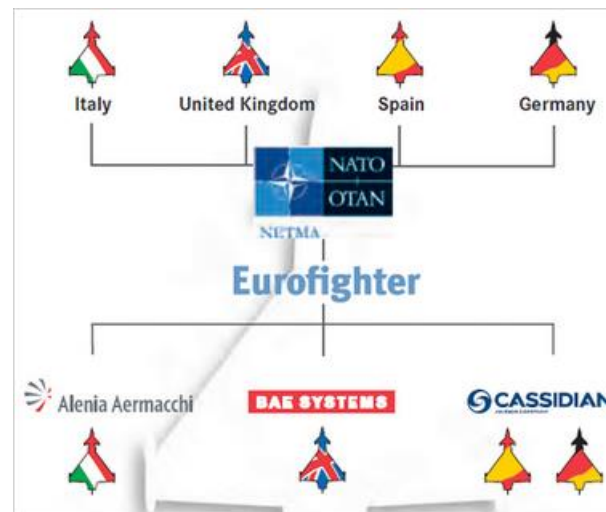


Figure 15: Eurofighter organisational structure (Source: Eurofighter Jagdflugzeug GmbH, 2013, p. 53)

contractual agreement with MoD to provide aircraft availability for five years (BAE Systems, 2013), ending in 2014 with the prospect of renewal. Several KPIs were in place to assess BAE Systems' compliance with the contract. In parallel to the availability contract BAE Systems was subjected to a second contractual agreement to ensure spare parts support for the aircraft's expected operational lifetime.

The support contract, as depicted in Figure 14, is governed by the Eurofighter/NETMA consortium, which is shown in Figure 15. It is cascaded from the UK MoD (designated "United Kingdom" in Figure 15) through NETMA and Eurofighter into BAE Systems and further on to GE Aviation and GE Aviation's sub-suppliers. The performance requirement for GE Aviation is an average repair turnaround time (RTAT) for the MHDD. At the time of writing the company shown as "Cassidian" in Figure 15 has been rebranded "Airbus Military" (Kaminski-Morrow, 2013). Further information on the Eurofighter Typhoon and the Eurofighter and NETMA consortium can be found in Eurofighter Jagdflugzeug GmbH (2013), Jackson (2010), and Ashford *et al.* (1996).

2 Case study design

Planning of the empirical case study followed to a large extent the process suggested by Yin (2009, p. 81) through a case study protocol that comprises an

overview of the case studied, including relevant literature, field procedures, case study questions and a guideline to how to report about the case study.

2.1 Conceptual foundation

The conceptual foundation is what Yin (2009) calls the “theoretical framework”. It represents the theoretical underpinning of the case study. Here, ‘conceptual foundation’ has been chosen because not one specific theory is followed or tested in the case study. Rather, the study is based on the relationships between knowledge, activities and cost ‘layers’ as shown in Figure 16 (Newnes *et al.*, 2013). Such relationships are built on the findings that PSS can be represented by the flow of material and information between processes, as well as performance resulting from actions (or activities). Explicitly linked to availability contracts, Erkoyuncu *et al.* (2011, p. 132) refer to the flow of knowledge and information over a service network. In Figure 16 knowledge is shown on the bottom layer underpinning the activities within the network of operations. Knowledge is considered an enabling condition to carry out any activity in the network of operations (Remus, 2002), while information can be interpreted as an explicit representation of knowledge (Keane and Mason, 2006, p. 4). An analysis of knowledge flow as a foundation of activities for the purpose of business process redesign is presented by Yoo *et al.* (2007).

On the second layer in Figure 16, the network of interlinked activities, resources are consumed, exchanged and transformed (Hansen and Mowen, 2003). The attribution of monetary value to the consumed resources is the task of costing, creating the third layer.

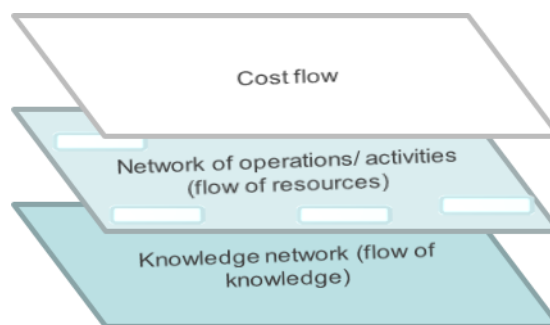


Figure 16 Knowledge, activities and cost: the three layers constituting the PSS.

Activities or processes are considered to be the elements constituting the PSS. To identify the relevant elements, the case study is set out to identify knowledge, information and material flow between activities. In this way, activities that cannot be directly observed, or are not referred to explicitly by interviewees can be identified through the flow of information towards them. Also, the creation of information, for example in the form of documentation is a result of an activity or activities. Therefore, the flow of information can reveal processes that otherwise could not be identified.

In addition to information, knowledge as embedded in people, commonly called 'tacit knowledge' plays a crucial role (see for example Gourlay, 2006). While tacit knowledge may not be externalised it carries 'know-how' that is crucial for performing activities (Darlington, 2003, p. 107). Therefore, the 'flow of tacit knowledge' through people moving between processes represents significant relationships between system elements and plays an important role for the identification of activities.

Another type (or dimension) of knowledge which resides somewhere between the tacit and the explicit knowledge is defined as "*implicit knowledge*" by Darlington (2003). Implicit knowledge is not externalised but can be 'raised above the surface' through careful enquiry. In this empirical study, conversation that is not recorded or written down is considered as implicit knowledge, such as informal dialogues between colleagues.

In the initial conceptual foundation of the case study, *data* was understood as information taken out of context, for example as signals coming directly from sensors (Glazer, 1991; Bohn, 1994). However, considering the formulation used by Glazer, "*Information' can be defined as data that have been organized or given structure – that is, placed in context—and thus endowed with meaning*" (1991, p. 2), one could argue that data is meaningless information. It is therefore questionable how 'useful' meaningless information can be. A discussion about the usefulness of different definitions of knowledge types and/or dimensions is beyond the scope of this work. Nevertheless, the concept of data, played a role in the *design* of the questionnaire, and as discussed later, 'useless' information was mentioned during the interviews (see section 5).

The conceptual foundation is based on the assumption that a PSS can be represented as a flow of people carrying tacit knowledge, implicit knowledge and externalized information between processes that are formed of activities. Furthermore, it is assumed that through the identification of activities knowledge flows can be identified and vice versa.

2.2 Unit of analysis & unit of data collection

There is a distinction to be made between the unit of analysis and the unit of data collection (Yin, 2009, pp. 88–89). Here, the unit of analysis is ‘the PSS’, i.e. the processes and their relationships in terms of material, information and knowledge flow constituting the PSS. Due to the specific conditions of the case, the researcher was not able to directly observe these. Therefore, the unit of data collection are individuals who work for GE Aviation or BAE Systems and are involved in the delivery and sustainment of the MHDD installed in the Eurofighter Typhoon.

2.3 Design of the questionnaire

The questionnaire was designed as a guideline during one-to-one semi-structured interviews to be used in combination with process maps that could loosely follow the IDEF0 standard to facilitate communication. Its rationale is based on the conceptual foundations outlined above in section 2.1. The initial assumption was that each individual interviewee could be assigned to a specific process covering multiple activities. During the research it became evident that such one-to-one association between interviewee and process could not be achieved. Therefore, the questionnaire was interpreted more openly to identify activities that could be aggregated to processes without *one* specific process owner.

The questionnaire is divided into clusters of questions that address different characteristics of PSS that seemed relevant to the case. During the research process the questionnaire was updated several times. The changes reflect experiences that some questions were understood by interviewees as repetition of previous questions. In the particular case of awareness of the interviewee about monetary expenditure, further clarification was needed about what that awareness was based on. This seeking clarification on the sources of the interviewees’ knowledge is a major difference to other works that use questionnaires as a means for data collection, see for example Dunk (2004) and Aston Business School (2013).

In the following the structure of the questionnaire and the main areas of interest are described:

- I. Personal information
Personal information included the job title, time in the job, responsibilities and day-to-day activities.
- II. Process internal / Knowledge required to “get the job done”
This set of questions aims at the knowledge, information and data required for a process to work. During the research it became evident that the questions in this section were often answered when the interviewee described his responsibilities and day-to-day activities.
This cluster of questions was informed by literature on process-oriented knowledge management, as for example Jochem *et al.* (2011), Gronau *et al.* (2005) and Maier and Remus (2002).
- III. Process performance
The relevance of performance indicators in availability contracts is explored in this set of questions. In addition to the literature listed for the cluster of questions above, the comparison of competence and maturity models by Ahlemann and Teuteberg (2005) contributed to this set of questions.
- IV. Knowledge flow to other processes
The creation of, for example documentation that is needed in processes other than the one the interviewee is involved in is thematised in this cluster. Questions concern the perceived usefulness of the created information for the receiving process and the effort spent to create the information.
- V. Knowledge flow from other processes
Here, the aim is to identify sources of knowledge and information, and depict them on the maps. One of the questions is about the need for ‘inofficial’ knowledge sources.
- VI. Knowledge quality
In how far the interviewees perceive that the knowledge and information they have access to, is useful to them and how they would rate the quality of the available information and knowledge is explored in this cluster of

questions. In addition it is asked for desired but currently unavailable information and knowledge.

This set of questions was motivated from references such as Bohn (1994), Johansson *et al.* (2011) and Strauch (2007).

During the research the questions about knowledge quality were integrated into other clusters, because often the quality questions appeared as repetitions of early questions. Also, during the research the focus changed away from rating the quality of knowledge and information. Therefore, knowledge and information quality was given less priority during the later interviews, in particular when time constraints limited the number of questions that could be discussed.

VII. Shift towards availability provision

Two questions in this set aimed to explore what the changed business model, from selling products to providing availability *meant* to those involved in terms of required knowledge and information.

Literature on servitization, especially that focuses on the 'transformation of people' provided the background for this set of questions (Ng *et al.*, 2011a; Ng and Nudurupati, 2010; Ng *et al.*, 2009).

VIII. Link between knowledge availability and resource consumption / awareness about monetary expenditure (modified)

This set of questions attempted to establish whether participant would see a connection between the knowledge and information they have available and the resources consumed in their activities. It was discovered that it was not a question interviewees were able to answer. Therefore, focus was directed to the participant's awareness about monetary expenditure and how such awareness was achieved. Additionally, the participants were asked what they would consider important to estimate the cost of the activities they were involved in.

Literature consulted for this set of questions included Serpell (2005; 2004), Datta and Roy (2010), Cooper (1990), Emblemssvåg (2003) and Han (2010).

IX. Knowledge about the contract (added)

During the interviews 'the contract' between GE Aviation or BAE Systems, depending on which organisation the respective interviewee worked for, and 'the customer' emerged as a recurring theme. 'The customer' could be any organisation that would receive products or services from GE Aviation

or BAE Systems. Therefore, questions about knowledge of the relevant contract and where that knowledge came from were added to the questionnaire.

X. Any other business

Before ending the interview the interviewee was given the chance to add anything he or she considered relevant, also off-record.

Before conducting the first interview (see section 4.4.1, Pilot interview) the questionnaire was discussed with an experienced researcher and among peers. Changes, in particular to how questions were formulated, were implemented to find the best agreement between what the researcher wanted to ask and what the test group suggested.

3 Research quality

For the present research the insight that there is little hope for complete knowledge about socio-technical systems (Hollnagel, 2012, p. 4) is crucial for the selection and application of methods and for questions about validity and reliability. It means, that according to Wilson (2001, p. 4) there are no *“unique, valid, and non-contentious descriptions”* of *“the real world of human activity”*.

While models of socio-technical systems cannot be proven or validated, they *can* be verified or calibrated by empirical data (Woltjer, 2009, pp. 24–25). Hence, it is more about the *“defensibility”* of a model (Wilson, 2001) than it’s *“truthfulness”* (Lützhöft *et al.*, 2010, p. 537). Throughout the research process the process maps were updated with insights gained during the data collection and analysis. While ultimately, it is the usefulness of a model to contribute to the formulation and understanding of a problem that determines its value (Größler *et al.*, 2008, p. 381), there are quality measures that can be applied to research relying on qualitative data analysis. Lützhöft *et al.* (2010) propose the hermeneutic concepts of credibility, transferability, dependability and confirmability for such research in the human factors domain. Similarly, Eisenhardt (1989) highlights the importance of grounding findings in the evidence while providing information on sample, procedures for data collection as well as data analysis in case study research. Table 17 outlines how these criteria were addressed and where they are presented in the following sections.

Table 17 Quality criteria (adapted from Lützhöft *et al.*, 2010, p. 537).

Criterion	Criterion as interpreted	What has been done to achieve criterion
Credibility	Show conformity between data and researcher's reconstruction	The concepts and their relationships representing the qualitative model are grounded in quotes, as presented in sections 5.2 to 5.5. The specific case setting did not allow for in-depth observation or extended engagement within the organisations.
Transferability	Provide thick description from which generalisation can be derived.	The case description as well as naming of the concepts and relationships constituting the process model should allow readers to compare the specific findings to other cases, see Part V, sections 1 and 2. However, the aim here is not to generalise or immediately transfer the findings to other settings.
Dependability	Transparency of research process.	The research process comprised: the design of a questionnaire for semi-structured interviews (section 2.3 details the topics addressed); a pilot study which concluded that the questionnaire was appropriate, see section 4.4.1; sub-subsequent interviews with 16 persons who were involved in the delivery of the MHDD, section 4.4; Sampling is discussed in section 4.1.
Confirmability	Show that data and findings are rooted in contexts and persons apart from the researcher.	By discussing the maps with the interviewees the researcher's interpretations were verified against the understanding of those involved in the PSS. Therefore, while the maps are a reflection of the analysis as carried out by the researcher, they are rooted in the view of those involved in the PSS (see sections 5.2 to 5.5).

With regards to the transferability of the findings presented in this paper, Johnstone *et al.* (2009, p. 534) caution that transferring findings from one setting to another might be “*deeply flawed*”. In this study transferability as a quality measure holds through a description that provides context and details to allow for an insightful comparison with other cases. It is important to highlight that such description is not a replacement for the formulation of a problem in a specific context. The selection of semi-structured interviews supports the criterion of transferability through rich descriptions of the phenomenon.

4 Data collection

Data collection started in June 2011 with the introduction of the researcher to the CATA project. Most of the early data comprised presentations given by GE Aviation and BAE Systems contact personnel, either during formal project steering meetings or more informal working meetings, some of which are in the following

referred to as unstructured focus groups. In early 2013 the first semi-structured interview was conducted.

Interviews in general pose challenges to the criterion of confirmability, as they are based on the interaction between the interviewee and the interviewer, which is specific to that occurrence contextually and temporally (Payne, 1999, p. 96). Considering the novelty of each interaction it is unlikely to be exactly reproducible (Hargie and Tourish, 1999). Therefore, the interviews were supplemented by IDEF0 process maps, see “Appendix D” for examples of IDEF0 maps that were used during the interviews. In this way the researcher and the interviewee were able to visualise their ideas, to place them in context, and the interviewee could verify the researcher’s understanding of the situation.

4.1 Sampling

Throughout the research, meetings with the contact persons from BAE Systems and GE Aviation provided alignment between the researchers and the industrial partners, for example for getting access to personnel in specific roles that emerged from previous interviews.

All interviewees were employed either by BAE Systems or GE Aviation and their responsibilities included activities that affect the delivery of the MHDD to the end user. They represent a cross section of functions and hierarchical positions from director level to shop floor technician.

Sampling differed between the two organisations. In GE Aviation snowball sampling (Denscombe, 2010) could effectively be employed after identifying initial interview partners. Even though the process of identifying knowledgeable and relevant participants in BAE Systems was similar in principle, it proved to be more difficult to pin point suitable individuals due to organisational intricacies. The criteria to assess whether the sample provided “*enough*” information to fulfil the characteristics of an exploratory sample (Denscombe, 2010) therefore also differed. Within GE Aviation that assessment was made based on feedback from the interviewees whether any relevant processes were missing. Whereas within BAE Systems the criterion was to capture the chain of communication required for delivering the MHDD from the interface with GE Aviation to the interface with the end user. Due to organisational and contractual intricacies within BAE

Systems one link on the support side between GE Aviation and BAE Systems could not be established first hand. Nevertheless, it is felt that the conducted interviews provided sufficient insights to fill this gap. Marschan-Piekkari *et al.* (2004) discuss interviewing in multi national cooperation and find that getting access to multiple sites can be facilitated by contact persons that are high in the hierarchy. Here, such approach was indeed useful in GE Aviation, whereas in BAE Systems the organisational structure prevented such an undertaking.

4.2 Ethical questions

This section follows key questions to determine how to address ethical aspects of the study as suggested by Sapsford and Jupp (2006, pp. 311–312):

- 1) *Are there ethical and/or political issues involved in the choice of research problem or the selection of particular samples to the exclusion of others (for example, in highlighting the interests of certain groups and ignoring those of other groups)?*

While it can be assumed that the organisational setting is not free of political issues, the researcher was not aware of any problems that could arise through the selection of particular samples. Only the research itself could give an insight of what the selection of a particular sample could mean. Ethical issues were not expected and did not arise.

- 2) *Is the research sponsored, and are sponsors influencing the way in which the research problem is being defined, the way in which the research is designed, or the ways in which the data are likely to be interpreted and used. Should measures be taken to reduce the sponsors' influence? If so, what measures?*

The organisations involved in the research, the UK MoD, BAE Systems and GE Aviation contributed to the definition of the scope and aim of the overarching CATA project. No specific limitations on this work were imposed. Interview records and transcripts are protected and were not made available to the organisations. Access to interviewees crucially depended on the BAE Systems and GE Aviation contacts and their ability of to arrange time with the participants. While not all individuals identified by the researcher could be interviewed due to

hierarchical gaps, at no time did the industrial contacts refuse an interview request.

- 3) *Is it anticipated that subjects of research will be harmed (for example, by research procedures such as withholding treatment from some subjects)? If so, does it matter that they are harmed? For example, is it believed that benefits derived from the research will outweigh potential harm to subjects? Is it considered that the research subjects do not deserve protection from investigative social research?*

No harm to the participants was anticipated and to the best of the researcher's knowledge no interviewee experienced negative consequences from participating in the research.

- 4) *If it is felt that subjects should be protected, what precautions can be taken to reduce or prevent harm (for example, promises of confidentiality or anonymity)?*

The research aim, to represent a PSS 'as is', includes showing elements or relationships that may not be designed or correspond to approved procedures. Therefore, there was a need to ensure that statements cannot be traced back to the individual interviewee. This need was addressed by anonymising the interview recordings and transcripts. Additionally, due to the small and specific sample (see "Sampling"), there is no reference made to the specific position of an interviewee when quotations are used in reports (including this work). The issue of interviewee protection in a small sample is further problematized by Payne (1999).

- 5) *Should consent be obtained before research is carried out? If so, from whom should this consent be obtained (for example, from subjects themselves, or from gatekeepers to such subjects)*

Informed consent forms were signed by every interviewee (see Appendix A for the Informed Consent Form).

4.3 Unstructured focus group interviews

Before conducting semi structured one to one interviews an initial understanding of the problem domain was achieved through several unstructured focus group

interviews (Denscombe, 2010, pp. 176–177). These – conducted among experts from BAE Systems as well as GE Aviation – contributed to the selection of the initial one-to-one interviewees. The procedure of the unstructured focus groups reflected relatively informal working meetings of the CATA project. Generally, the participants from GE Aviation, BAE System and the MoD would outline their view on the current situation, where they saw the challenges and what they ‘hoped’ for how these challenges could be met in the future. The researchers asked questions seeking clarification on the case setting as well as how the research would achieve relevance for practice. Personal notes and minutes is the data collected from the unstructured focus groups.

4.4 Semi-structured interviews

17 one to one interviews were conducted between January 2013 and February 2014. 16 of the 17 interviews were transcribed and used for the analysis. Not transcribed was one interview with a participant from BAE Systems whose responsibilities lie outside the TAS contract and was therefore considered out of scope. Each interview was between 30 minutes and 2.5 hours long. Most interviews however took about 1 hour.

In general, all interviews followed the same process:

1. The researcher set up the room in advance which included placing the relevant material on the table, and whenever possible arranged for some drinking water available on the table.
2. Introduction to interviewee, usually through one of the contact persons, followed by a short description of the CATA project and this particular research.
3. Time to ask questions.
4. Interviewee signs informed consent form that assures confidentiality of the individual’s statements. Because of the distinctly different positions held by the individuals direct quotations invoked in the following sections are generally not attributed to the interviewee’s position within an organisation to fulfil the interviewer’s responsibility for interviewee protection (Payne, 1999, p. 95).
5. Start recording.

6. Explanation to the concepts knowledge, information and data. It was felt that these concepts needed some explanation because the daily use of these terms can be quite ambiguous. For example 'knowledge management' can easily be associated with databases and not with the skills of individuals. To illustrate what the researcher meant by knowledge, information and data, a chart with examples of these concepts was shown to the interviewee (see Appendix C).
7. Start interview with personal information.
8. Interview along questionnaire as guideline, the use of the IDEF0 maps varied. In general the process maps were shown to represent to current view of the researcher and the interviewees comments were immediately sketched onto the hardcopy. Also, during the interview process the interviewees were encouraged to sketch the activities they described and relationships among them.
9. Finish interview with an opportunity for the interviewee to add anything he or she felt was that important but was not addressed by the interviewer.

In general the interviewees were allowed to elaborate on what they considered important rather than completing the questionnaire. Therefore, due to time constraints not all questions were asked or answered in all interviews which does not pose a major concern because the focus was placed on 'discovery', rather than 'checking' preconceived themes. Tightly scheduled meeting room availability lead to interviews being interrupted and, in one case, broken off. In general, the context interviews are conducted in is considered part of the process, and not as something that can be eliminated under 'ideal' circumstances (Warren, 2002, p. 91).

4.4.1 Pilot interview

Johanson (2004, p. 3) portrays a situation in which a significant gap between the interviewees' and the interviewer's viewpoints emerged during the interview:

"The interviews revealed an enormous gap between our worldviews. The managers obviously thought I was completely ignorant of reality. And I never got answers to my questions."

To prevent a situation similar to the one described above, once the initial questionnaire was developed a suitable interview partner in GE Aviation was identified to test the suitability of the questionnaire. Of interest was whether the questions made sense outside the academic environment and whether the interviewee would provide answers that would broadly fit the researcher's expectations. Additionally the pilot interview was a test for the recording equipment, the informed consent form and the interview procedures, including the use of IDEF0 process maps. As a result of the pilot interview a new dictaphone was purchased. All in all, the pilot interview proved successful and the questionnaire was used in the following interviews with continuous improvements throughout the research process. Also, the use of IDEF0 maps was considered useful by the interviewer and the interviewee during the pilot interview.

4.4.2 Creation of maps

During the interview process the interviewees had the chance to challenge the researcher's understanding of the specific context, as shown on IDEF0 hardcopies and to modify the maps according to their knowledge. In this way the findings are rooted in the specific context and reflect the views of those involved in delivering avionics availability. Hence, the maps support confirmability of the research.

Initial maps were based on the unstructured group interviews and on experiences by one of the academic collaborators from the CATA project related to a comparable case (Parry, 2010). One particular challenge was mapping of the activities on the airbase. Since the researcher could not get direct access to personnel working there or to the site itself, he had to rely on secondary accounts following a visit by just one of the CATA researchers. The maps based on these insights were subsequently discussed and updated with an interviewee from GE Aviation who frequently visits the airbase. During most interviews the maps were discussed and updated by the interviewer in agreement with the interviewee in the beginning or through-out the interview. The IDEF0 representation assisted in familiarizing the researcher with the organization-specific language, and the hierarchical structure and gradual introduction of detail in IDEF0 facilitated focusing discussion during the interview on the areas of expertise of the respective

interviewee. In general, the sketches used and produced during the interview did only loosely follow the IDEF0 standard for practical reasons.

4.4.3 Transcription

Through transcription audio records are made available for text analysis. The transcription process poses technical as well as methodological challenges and cannot be considered straightforward. Also, transcripts are always *interpretations* of the audio recording (Poland, 2002; Denscombe, 2010, p. 278).

Transcribing interviews is very time consuming, in this research about 8 hours transcription time was required for 1 hour interview time. All interviews (being conducted in English) were transcribed by the researcher, a native German speaker, using QSR International's NVivo 10 software. No voice recognition software was employed. Several challenges were encountered in the process:

- 1) Clarity, more often related to an interviewee's accent than to recording quality;

Unclear passages were listened to several times at different playback speeds, in the wider context and the passage in isolation. In many cases a reasonable interpretation of the recording could be 'found'. However, sections that remained unintelligible for the researcher were marked and coded carefully to avoid opportunistic interpretation to fit a particular theme. (Themes are coded to nodes in NVivo 10).

- 2) Endless sentences;

It is common that interviewees do not speak in finite, well-structured sentences (Denscombe, 2010, p. 276), and such was the case in most interviews. Therefore, punctuations had to be introduced to structure the statements. While this practice represents an interpretation of the researcher, the punctuations are based on the rhythm of the speech. Hence, the structured transcription reflects the meaning better than unstructured endless sentences.

- 3) Indirect speech;

Related to the above, but sometimes hard to recognise is indirect speech. Interviewees frequently switched the perspective from talking about themselves to talking about someone else, without being explicit about it. Whenever recognised during the transcription or during the

coding inverted commas were introduced to reflect indirect speech in the text, for example *"Cause when we set up a contract it's normally say 'you will supply however many aircraft plus support for a period', it's normally 25 years"* (indirect speech in non-italics).

4) Unfamiliar words;

Due to the researcher's native language being German unfamiliar words were encountered occasionally. In most cases these could be clarified with the help of native English speaking colleagues and the online dictionary "Beolingus" (<http://dict.tu-chemnitz.de/>). For the researcher an unknown word can be hard to identify as such. Therefore, it can be assumed that unfamiliar words might have been treated as unclear passages, which means that they were marked as such and coded accordingly.

5) Idioms;

Idioms are expressions and terms whose meaning cannot be directly derived from the meaning of the individual words, such as metaphors (Lister and Veth, 1999). For a non-native speaker these can be impossible to understand but also hard to identify, for example *"...swings and roundabouts..."*. Whenever a passage appeared to be clear but did not make sense to the researcher, native speakers were consulted.

In general all interview recordings were listened to several times, during transcription and during the analysis. Whenever mismatches between the recording and the transcript were identified, the transcript was amended. While correct spelling was not willingly ignored, it is common that words such as 'I' or weekdays are spelled with small letter, to facilitate and accelerate typing.

The transcriptions were directly entered into NVivo 10 and tagged with time stamps according to the audio recording.

4.4.4 Thematic analysis

The main purpose of the analysis was to create a qualitative model of the PSS based on an IDEF0 representation showing information and material flow between activities or functions. After transcribing the interview recordings the transcripts were coded using NVivo (Richards, 1999). Codes were arranged in

Table 18 Coding examples

Time	Content	Comment on coding
...	...	
33:09.7 - 33:22.6	You mentioned performance, making performance visible. And you said that you are measured, you have the 30 day turnaround time. Do you have other performance metrics that you are measured against?	All coded as "Interviewer" & "Process performance"
33:22.5 - 34:21.8	Well, I have sort of an informal measurement about time to submit a non-accountable form to the customer. So, obviously they are interested in getting a quote of that, and a non-accountable form including some images of the damage to the item within 30 days basically, if not a lot sooner. It is something we work to. In fact, we have actually managed to decrease that massively by really sort of intervening more personally. So, within the first instance, rather than letting something go all the way through to the shop and then it getting maybe held up there, because they are dealing with the in-scope repairs before the damaged repairs, if you see what I mean. So, that's one other thing that we ... as well.	All coded as "Interviewee XYZ" & "Process performance" "...by really sort of intervening more personally. So, within the first instance, rather than letting something go all the way through to the shop and then it getting maybe held up there, because they are dealing with the in-scope repairs before the damaged repairs..." Coded as "Repair routes" & "Repair activities" "...they are dealing with the in-scope repairs before the damaged repairs..." Coded as "Priorities"
...	...	

hierarchical themes that initially reflected the categories of the questionnaire, addressing the identification of activities and knowledge flow between them. During the research the focus of the analysis shifted towards how to represent the investigated setting. Hence, themes were added that reflected the elements of IDEF0 maps. Throughout, new themes emerged and themes were regrouped to organise them in the most meaningful way, as suggested by Bryman (2012). Themes that were used to build the maps are a result of deductive coding, reflecting the IDEF0-specific themes and inductive coding reflecting case-specific processes and links as well as themes that did not fall under the IDEF0-structure. An example for how the transcript was coded is shown in Table 18.

4.5 Company documentation

In the initial stage of the research contact personnel from BAE Systems, GE Aviation and the MoD presented their view on the current state of the TAS, and the case setting. Additionally, the unstructured focus group interviews in most

cases comprised presentations by industry personnel. These presentations were accessible to the researcher, however they are considered as confidential. This situation applies to most of the documentation the researcher received throughout the project.

Other types of documentation, apart from presentations comprised process flowcharts, and spreadsheets containing repair and Failure Reporting, Repair Analysis and Correction System (FRACAS) records (more information on FRACAS is provided by Smith and Keeter, 2010). Organisational charts from BAE Systems supported the selection of suitable interviewees.

4.6 The researcher as a research tool

Rarely discussed in the literature about PSS, be it in the domain of cost engineering or management, is how the individual researcher might have influenced the research process. In this research, the researcher's previous work experience in aviation proved to be beneficial for the communication with interviewees and during project meetings. Nevertheless, specific terminology, acronyms and lacking practice of the interviewer in the specific context affected the interviews to varying degrees. It is the researcher's opinion that potentially details were missed out but that the essential information was still conveyed in layman's terms rather than specific terminology.

Hargie and Tourish (1999) elaborate on the psychology of inter-personal skill in an interview situation. Among the most challenging aspects in this research was that each interview creates a novel interaction between the interviewer and the interviewee, and the majority of the interviewees were unknown to the interviewer before the interview started. Time constraints required the interviewer to quickly build rapport with the interviewee to create an atmosphere that allows for open questioning and answering. In the context of different cultural backgrounds, which applies in this research, Ryen (2002) highlights that the interviewer and interviewee actively co-construct meaning and define what they represent to each other. A brief and un-recorded introduction of the research in general and the interviewer's role in particular, followed by time for the interviewee to ask questions was perceived by the researcher to generally facilitate the creation of such atmosphere.

Semi-structured interviews give the researcher the chance to probe ad-hoc where a topic might require more explanation or where contradictions arise (Denscombe, 2010). The ability to listen and ask follow-up questions, in particular when unknown or unfamiliar terminology is used can be quite challenging for the interviewer in particular in a situation of linguistic disadvantage (Marschan-Piekkari and Reis, 2004). All interviews were conducted in English and reflected a situation of linguistic advantage for the interviewee, as the interviewer's native language is German. From the interviewer's perspective, only during the process of transcribing the interview recordings missed opportunities for probing were identified. During the interview the constant need for attention to comprehend the interviewee's responses, to place them in the context of the questionnaire and to react with follow-up questions occasionally prohibited asking probing questions that would have gone into further detail of the interviewee's response.

5 Results

This section presents the results from the analysis of the collected data. Most findings are derived from the semi structured interviews. However, where possible they are integrated and verified through company documentation such as process maps and organisational charts. The raw data is not shown here to account for the confidential character of the information provided.

5.1 Document analysis – a rich picture

The most influential document for shaping this research from the beginning is shown in Figure 17. The representation fits Checkland and Scholes' (1999, p. 45) description of a rich picture that conveys the correct 'feel' of the situation by adequate symbols to express relationships while taking into account that the existence of many such relationships precludes an immediate solution. It was created by BAE Systems "*as a vehicle to 'bring to life' some of the very complex business activities that BAE Systems and our people*" were involved with as a means of internally communicating the Engineering Strategy for the future (BAE Systems, 2014). Apart from Figure 17 other rich pictures were created by BAE Systems that visualise other areas of the functions provided by the organisation, such as support and changes in strategy (BAE Systems, 2014). Having seen two of these other representations, the author considered Figure 17 as most insightful in terms



Figure 17 A rich picture showing the delivery of advanced services as interpreted by BAE Systems (Source and copyright: BAE Systems).

of the activities undertaken for providing aircraft availability and by which means these activities are linked.

Figure 17 shows the delivery of frontline and supporting services resulting from interlinked activities carried out by people who communicate and use data and information. Material is transported to where it is required as a result of this flow of information. Since the figure conveys the idea that those people involved play a crucial role as enablers for the delivery of the desired outcome, this interpretation of a PSS contributed to the selection of the research approach including the methods for data collection. Also, the conceptual foundation of the case study is influenced by the represented flow of material and information as shown in Figure 17. The knowledge and activities layer in Figure 16 is an abstract reflection of what is shown in the form of concrete examples in Figure 17.

5.2 Organisational findings

The representation of avionics availability in a qualitative model requires the identification of elements, and links between these. Here such elements and link are translated into activities (or processes) and information and material flow. Nevertheless, the organisations involved represent an intermediate step from the primary unit of data collection, the interviewees, to the unit of analysis, the PSS delivering avionics availability. Therefore, the following sub sections summarize findings related to GE Aviation and BAE Systems.

5.2.1 BAE Systems

Within the scope of this research are the parts of BAE Systems that are involved in the Eurofighter Typhoon program and more specific those parts that interact with the UK MoD, the RAF and GE Aviation; not BAE Systems as a whole. Through the course of the research it became clear that for the Eurofighter Typhoon BAE Systems fulfils a double function. As part of a multi-national consortium BAE System is involved in the manufacturing, final assembly and selling of the aircraft and – in the focus of this research – they provide the availability of those aircraft purchased by the UK MoD and operated by the RAF. The organisational segmentation within BAE System, as shown in Figure 18 is one of the significant findings of this research and is the result of a critical reading of organisational charts and other evidences (and actually may not be aligned with the official organisational charts!).

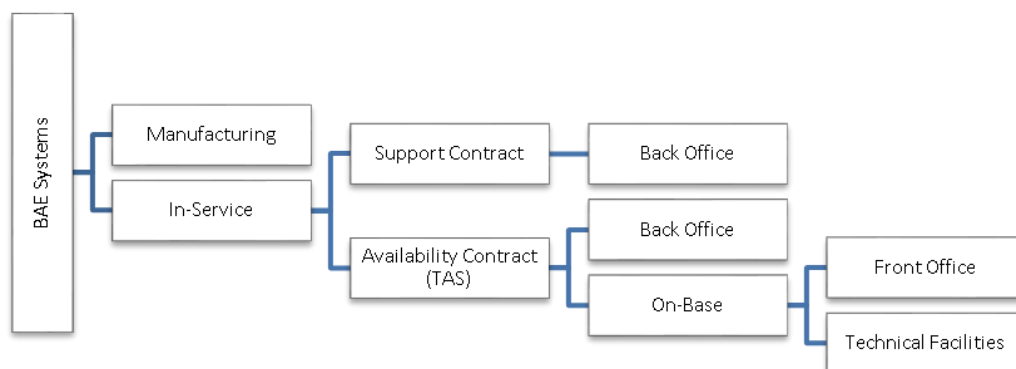


Figure 18 BAE Systems organisational segmentation

The split in BAE Systems between that part of the organisation that supports the aircraft and effectively provides its availability, and the manufacturing division is a major issue from the perspective of GE Aviation. *"So I have some good metrics that look sort of 360 [degrees] at the product to say how it is performing. But because of the nature of [BAE Systems], they would never have that data together on one bit of paper. So I can say 'there is an issue here we are starting to see in service' we can build something into production to make it better going forward, that's quite a sophisticated conversation to have with [BAE Systems]."*

Internally within BAE Systems, the separation between manufacturing and In-Service affects data availability for analysis because of the presence of two distinct contracts that mandate different levels of information provision from the suppliers. As expressed by an analyst: *"In-service is a repair contract, [...] the production side of things is a repair and investigate [...] contract. So you're always battling against that from an in-service point of view."* Figure 18 shows that the organisational segmentation of BAE Systems extends within the In-Service support being split between the Support and the Availability contract. While both contracts are worked through separate back offices, the availability contract additionally requires considerable engagement with the RAF on the airbase. This includes an avionics workshop (AWS), run by BAE Systems personnel, for pre-examining and testing of MHDD and other equipment.

By contrast, the support contract defines the relationship and performance metrics between BAE Systems and GE Aviation. Therefore, the links to GE Aviation are established through the 'Support contract-Back office' route in Figure 18. Within the Back Office, it was recognised that the chain of communication and interaction between those who deal with the customer and those who deal with the suppliers has been prolonged in the course of organisational and contractual changes. *"So over the last four or five years I guess we have gone from a very compressed supply chain to a real extended supply chain."* The same interviewee suggested that *"the shorter it is, the better it is. The further we get from the customer the worse it is for the job."*

Similarly, the flow of information about MHDD usage is affected by the split between Front Office, Back Office and the different contracts. An analyst highlighted that *"when you go down [to the airbase] and you talk to the guys who are actually maintaining it, you get a completely different view of how it's operating in*

service, than you do from what's put on failure reports [...]." However, the priorities of the BAE Systems division On-Site may not necessarily match those of the data analyst from the back office which is *"where you lose a bit of knowledge"* that could have been insightful for the data analysis. Reporting the results of analyses within BAE Systems was subject of discussion following the question whether the report sender had knowledge about how the report would be used. It was clear that even though that report would be considered by *"pinning it on their walls down there saying this is how we're doing service-wise", "feedback as to whether they are actually doing anything with it"* was absent.

Another perspective on the availability of information within the organisation was expressed from the Support Contract Back Office as *"we don't always understand what that information is but we are expected to understand it. And there isn't necessarily the education that allows people to fully understand what it means. And then even when they do, there is always the danger of the 'so what?'* So how does that help me? Now, it might help somebody way of in a different set of offices somehow but may or may not have an impact on how the end customer gets his piece of equipment."

As a result, within BAE Systems and in particular within the In-Service support an integrated view on the equipment performance and how to tackle arising problems is difficult to achieve. BAE Systems' organisational structure, reflecting the In-Service/Manufacturing and the Support/Availability Contract split exacerbated these challenges. At the time of writing a restructuring program is implemented in BAE Systems to overcome the In-Service and Manufacturing separation.

When it comes to payments from BAE Systems to GE Aviation, there are different routes depending on the type of repair. If covered by the Support Contract the individual repair is not billed separately but accounted for by an overall number of repairs purchased by BAE Systems up-front. A repair that is not carried out under that contract – for example a repair categorised as customer damage – needs individual pricing and agreement between BAE Systems and GE Aviation and additional order forms are required for those repairs to go ahead. Between BAE Systems and the MoD the route taken by financial transactions is determined by the Support and the Availability Contract. Within the Support contract BAE Systems *"gets paid through Eurofighter. Eurofighter has to ensure that they get paid through Netma"*. By contrast, funding comes directly from MoD to BAE Systems under the Availability agreement. The role of the MoD includes checking,

approving, and possibly challenging invoices issued by suppliers to BAE Systems. It was felt that there was a significant time delay between the issuing date of the invoices and the approval by the MoD, and that it would frequently cause rework within BAE Systems and their suppliers.

From a researcher's perspective the consequences of the two contracts for the organisational structure within BAE Systems, and the delivery of MHDD availability were not obvious. Statements like "*[The Availability Contract] looks at the total support solution but works it with [the Support Contract]. [The Support Contract] is not a part of [the Availability Contract].*" indicate that both are distinct but not separable. Looking at the final delivery of BAE Systems, the availability of the aircraft is governed by the Availability Contract. This is however affected by the activities carried out under the Support Contract which covers the MHDD and determines GE Aviation's engagement. Consequently, "*sometimes the [Support] contract gets in the way of providing availability*" as expressed by a BAE Systems employee. In general, knowledge about "*the contract*" was pointed out as essential for carrying out the interviewees' respective job. Section 5.5.2 discusses more details about the role of knowledge about the contract for the day-to-day work within GE Aviation and BAE Systems.

The investigation within BAE Systems revealed a complicated organisational structure, multiple contracts and different roles the organisation plays. The contribution of BAE Systems to the provision of the availability of the MHDD was identified as mainly administrative which is a consequence of the relationship between GE Aviation and BAE Systems being governed by the Support Contract. Also, it has to be highlighted that the Front Office and Technical Facilities on base could not be investigated due to access restrictions.

5.2.2 GE Aviation

GE Aviation builds and repairs the MHDD as well as other pieces of avionics equipment for the Eurofighter Typhoon for the RAF and other customers. Different pieces of avionics equipment may be linked to different sub-suppliers and customers may receive repairs under different contractual agreements. Hence, the activity space GE Aviation operates in is created by customer contracts, the equipment and sub suppliers, as depicted in Figure 19.

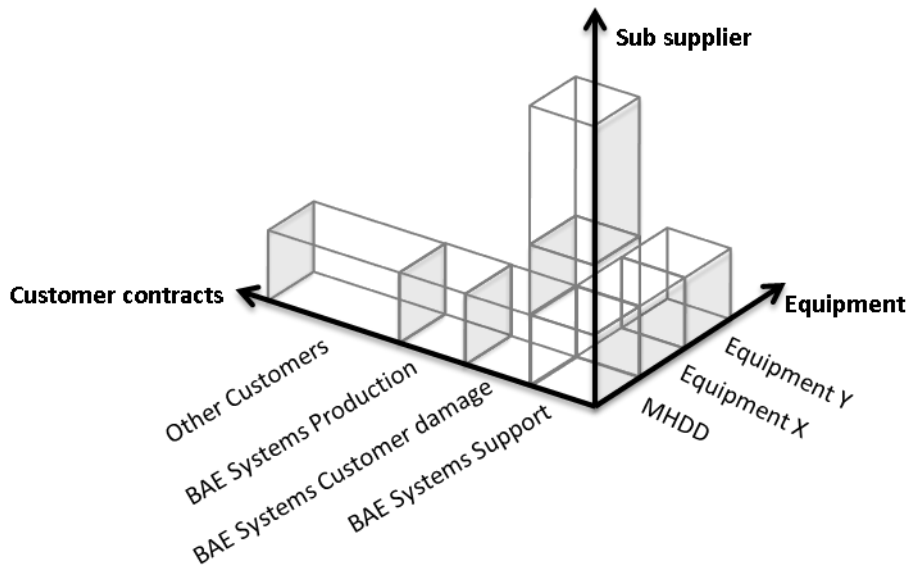


Figure 19 GE Aviation activity space

The activation of different resources and activities, depending on the contract leads to multiple routes of processing repairs, even for the same equipment, one of which is the MHDD. Variety is present even within the Support Contract with BAE Systems where different repair routes may be followed. In Figure 19 these routes are shown as ‘BAE Systems Support’ which is subject to a specified RTAT and ‘BAE Systems-Customer Damage’, where the repair time is not specified but agreed as ‘to the best of GE Aviation’s abilities’. A routine repair covered by the Support Contract requires administrative activities as well as physical handling of the equipment, such as testing and repairing and packing before the unit leaves the GE Aviation site. Administration is concerned with booking the equipment into an IT system that *“will record what was the fault that was found, was it confirming the customer fault, which [sub modules] were replaced, who the inspector initials were. [We also] put a ‘ready for collection’ [mark on the IT system], which then indicates to the customer it’s going to come out. Also in the [IT] system we will forecast a delivery date.”* Additionally, *“we have to raise [...] compliance paperwork, which would be ITAR paperwork, [that] says is there any ITAR components? And that is yes, have they been changed, yes or no. If they have been changed we record what licences.”* Further information on ITAR, the “International Traffic in Arms Regulations” can be found in Cook (2010), Wolf (2012) and Freebody (2013). The generation and dissemination of information is not perceived as requiring much additional effort

even though in specific instances the IT systems in use necessitate duplication of data entry. *“Our business system has to capture that data, and you can’t [copy] the data from the business system to the [Repair] System, because it is secure. And you can’t [copy] the data from the [Repair] System to the business system, so you got to duplicate the data there.”*

Themes (as coded in NVivo) related to the different repair routes in GE Aviation and their relationships are shown in Figure 20. Depending on the contractual agreement and the MHDD failure diagnosed repairs for different customers may

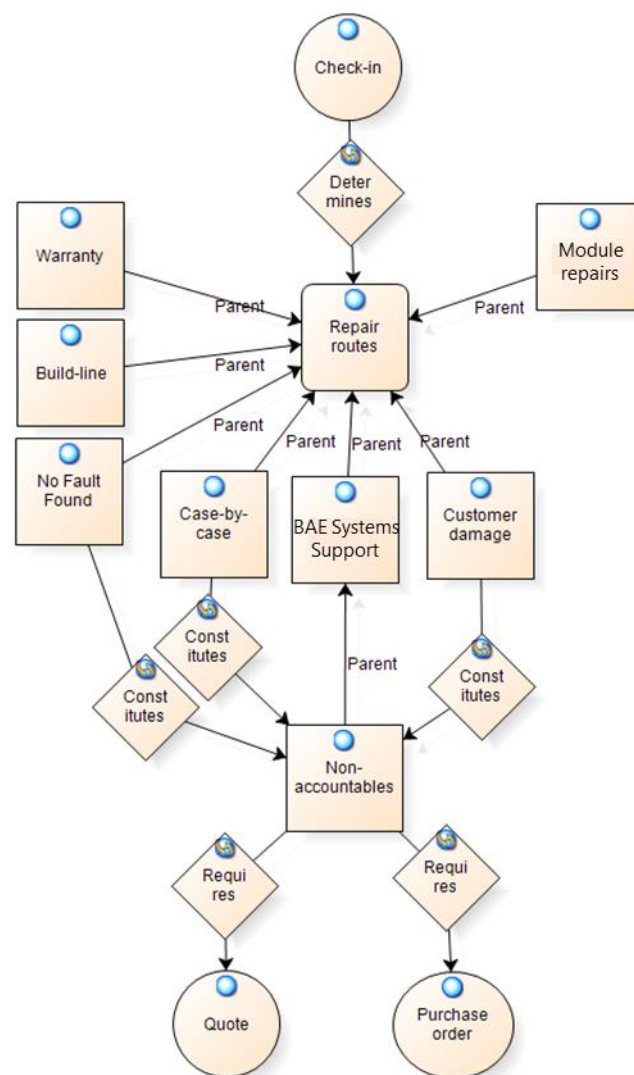


Figure 20 Themes and their relationships related to repair routes in GE Aviation.

be processed under these different routes. For example, 'Module repairs' are provided to certain customers who send defective sub modules rather than complete MHDD in to GE Aviation for repair. This route is currently not available under the BAE Systems Support Contract for RAF equipment.

In general there is an attempt to process repairs under the BAE Systems Support Contract as quickly and smoothly as possible which is facilitated by the fact that *"we're not going to be held up with documentation, we're not going to be held up with purchase order, we don't even have to quote, if it's [covered by the Support Contract], it goes straight through [to the] repair."* However, all this additional paperwork is necessary when repairs are processed as 'Non-accountables' (see Figure 20) and repairs that are required when the number of repairs per year purchased by BAE Systems is exceeded and a defective MHDD is repaired under a case-by-case agreement. Similarly, repairs that are caused by the equipment being mishandled and damaged by RAF or BAE Systems personnel require additional activities within GE Aviation and BAE Systems. As one of the GE Aviation contract managers said: *"... customer damage to me is a pain."* In such case, the normally streamlined process chain from booking a unit into the GE Aviation system, going through testing, repair and release is significantly prolonged, in particular by administrative activities. These include the creation of a quote for the repair, reaching agreement with BAE Systems on the assessment as customer damage as well as on the repair price. Additional activities may be required to understand the specific damage history, but also how the way of operating or handling the equipment may be improved to prevent similar events in the future. At this stage GE Aviation *"know what we would like to do and what we think would be good. We struggle to get the engagement on that [from BAE Systems]."* So while GE Aviation has the expertise and knowledge to suggest improvements, it is felt that these initiatives are not actively supported by BAE Systems. The need for agreement with BAE Systems and additional information from BAE Systems or the RAF can cause GE Aviation to struggle meeting the contractual RTAT, in particular when it is agreed that a repair is not classified as Customer Damage. For GE Aviation that can be worrying *"because we've got [that number of] days. [The question is] are you going to get that information from the customer in time to make sure you can still achieve your metric? And that's where [the RAF] tends to be ok, [other customers] not so good."* Thus, the contribution of the customer, here the timely flow of information is a

determining factor for GE Aviation's achievement of the contracted performance metric.

The role GE Aviation plays within the PSS is summarised from their perspective:

"We are very much a transactional sub-contractor providing repairs on a turn time. That's what we do. That's not what I would aspire to do but that's the way we work at the moment."

5.2.3 Material and information flow between BAE Systems and GE Aviation

In the following the links in terms of material and information flow that emerged between the organisations involved in the delivery of available MHDDs are discussed. Figure 22 loosely follows the IDEF0 standard, in that it shows an organisation-centred representation. Such view is opposed to the functional-orientated modelling as stipulated by the IDEF0 standard. An organisation-centred view illustrates more effectively *who* is responsible for which delivery, whereas a functional view is more suitable to illustrate *what* is done.

Figure 21 shows the stream of 'Functional MHDD' towards the RAF, depicted here from the Sub suppliers of 'Functional sub-modules' via GE Aviation, who builds and repairs the MHDD. Some of the test equipment in use at GE Aviation, for example "a golden unit" of an MHDD, "is owned by [the UK MoD]". BAE Systems is in the constellation shown in Figure 21 not directly involved in the

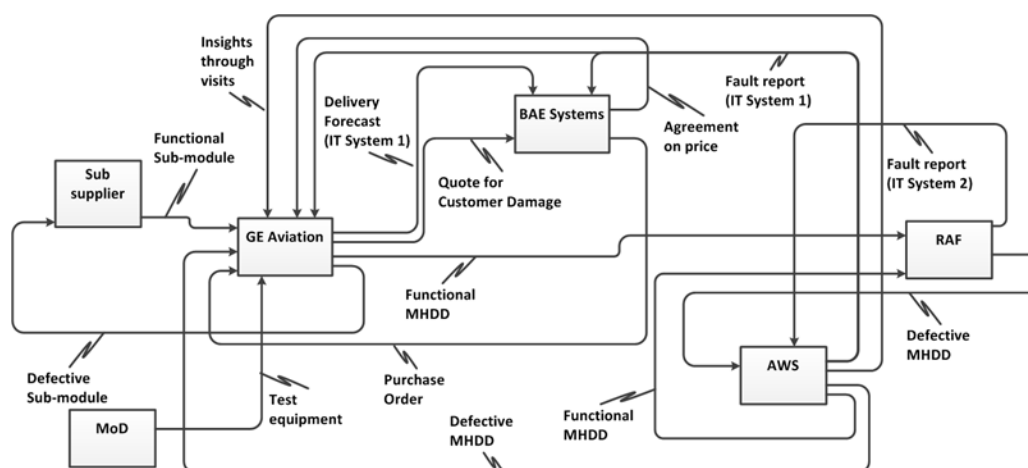


Figure 21 Material and information flow between organisations involved in the Support Contract.

material flow. Instead, the material flow *“will be facilitated by a messaging that happens between [BAE Systems and GE Aviation]”*.

In addition to BAE Systems and GE Aviation the avionics workshop ‘AWS’ is introduced in Figure 21. It functions as an on-base filter to survey and test equipment that has been labelled as defective by the RAF. As such the AWS may either return functioning equipment to the RAF or send it to GE Aviation for repair. In the latter case AWS is also responsible for transferring Fault Reports from a customer IT system (shown in Figure 21 as ‘IT System 2’) into the ‘IT System 1’ which is shared by BAE Systems and GE Aviation. The use of multiple IT systems leads to duplication of data and potentially a loss of insight about the operating conditions the equipment has failed in GE Aviation can achieve. The IT System 2 is populated as follows: *“... the pilot will come in, he will input what he has seen, he will say ‘here are my symptoms [...]’ [and] that all goes into [IT System 2]. All the work that is done to recover that aircraft is in [IT System 2].”* However, what is subsequently recorded however in IT System 1 is a result of a first level inspection and testing in AWS and *“then the bit he will put on [IT System 1] is ‘[the unit] has failed test 1, 2, 3’.”* Not only does this entry affect the repair process in GE Aviation but also the insights that can be gained by analysts in all organisations. It is up to the analyst to acquire further information to achieve better understanding about the specific context from the on-base personnel by personal interaction or verbal communication through the telephone. From the perspective of GE Aviation *“an accurate fault report would help”* with repairing the MHDD. However, *“we can do it without; we just run our own investigation”*. To proceed in that way means that tests that were already performed at the AWS may be repeated, and that troubleshooting may require more time and effort than it would with a precise fault description. Nevertheless, occasionally the information provided in the fault reports needs more detail or further explanation to carry out a successful repair. GE Aviation therefore *“have got people [...] who regularly go to the [airbase] and they can ask these questions.”* Accordingly, GE Aviation receives ‘Insights through visits’ from AWS as a control to their activities in Figure 21 which reflects these insights supporting the provision of successful repairs. In the worst case where no fault can be found (NFF) the equipment will be tested to the specifications, released and sent back as a functional unit to the RAF. In such case all resources that are needed

for a repair (except for spare parts) are employed while potentially the unit might fail again under the same or similar usage conditions.

Looking at the material flow, functional equipment flows towards the RAF from GE Aviation who receive functional Sub-modules from the Sub suppliers. The RAF also receives functioning MHDD from AWS, as described earlier. In the reverse direction one can see that GE Aviation, as well as the Sub Suppliers receive equipment that needs repair. This reverse flow critically determines their ability to feed the forward flow of functional equipment. It has been highlighted that both, the Sub Supplier, as well as GE Aviation struggle when they are confronted with a sudden demand for repairs. If for a sub supplier *“it tends to be the same module, there is a stock pile at the [sub supplier]. They are not used to [dealing with] the same material all the time.”* It then cascades down to BAE Systems, as one of their group leaders frames: *“...in a nice simple world you have one [functional] asset out, another asset [that needs repair] in. But the reality of life is that you have one asset in, one asset out. Then suddenly you have three more assets in, ‘oh, I haven’t got sufficient spares to get the three more assets [that need repair] out’.”* The situation might be exacerbated by a lack of visibility the BAE Systems Back Office as well as GE Aviation experience in terms of the location of MHDD units on base. This is manifested in the statement referring to the communication between BAE Systems and GE Aviation: *“...how can you be AoG [Aircraft on Ground] for this piece of kit? We have only got [this number]. We know you have got [so and so many] on stock, where is the rest of this?”, “we have no idea, we don’t know.”* Accordingly, the handling of material on the airbase, and the information about these processes is considered to have significant knock-on effect on the re-supply loop of MHDD to GE Aviation and its sub suppliers.

5.3 A functional view

Coding aimed at developing themes that can be translated into IDEF0 map elements. Table 19 shows themes representing the structure of IDEF0 maps and case-specific codes. In parallel to the thematic analysis the IDEF0 maps were refined by adding activities and relationships and introducing greater detail where relevant.

While the perspective on the delivery of available MHDDs shown in Figure 21 provides a good overview of the links between organisations, it does not provide insights into cross-organisational functions and mechanisms. Such insight is

Table 19 Themes associated to the maps.

Boundaries	Links (Inputs, outputs, controls)	Processes	Resources
	Knowledge flow <i>To other processes</i> <i>From other processes</i> <i>Desired</i> Material flow	Administration <i>Stock keeping</i> Data analysis & optimisation Delivery <i>Logistics</i> <i>On-base</i> <i>Repair activities</i> Governance	Non-dedicated

required to understand how socio-technical systems work (Snook, 2002, p. 223). As expressed by Geer *et al.* (2004, p. 325): “*In order to gain a holistic understanding we have to consider the parts and in order to grasp the parts we must have a concept of the whole.*” Therefore, the focus was moved away from the organisations towards the functions and the relationships between functions that enable the conditions for successful delivery of avionics availability.

From an IDEF0 perspective (National Institute of Standards and Technology, 1993) a system is described in terms of functions on different hierarchical levels. The highest level of the investigated setting is termed “top level functions”. These top level functions themselves consist of sub-functions when broken down. Therefore, top level functions can be considered as sub-systems comprising sub-functions and relationships. Therefore, in the following top level function may also be termed ‘top level sub-systems’.

5.3.1 Top level functions within the PSS

A functional perspective can be achieved following a description of the PSS by a BAE Systems analyst:

“... every time I need to send an item back to industry they use the [Support] contract, that item will be shipped and picked up and it will go straight to [GE Aviation for repair] but it will be facilitated by [BAE Systems].”

What is described here is summarised as a ‘Delivery’ function, where the equipment gets physically handled, as in transportation and repair, and an ‘Administration’ function that “*facilitates*” the delivery. The interviewee continues

to hint at a potential third high level function that constitutes the PSS providing availability:

“Then what you have is recognition that actually, could I improve or could I reduce the costs?”

The need to reduce costs and improve the current situation is interpreted as a third top-level function, called ‘Analysis & Optimisation’. A view on the PSS emerges that shows three top-level functions:

1. The ‘Delivery’ function where the hardware is physically handled;
2. The ‘Administration’ facilitating the delivery through documentation and IT-based information processing;
3. The ‘Analysis & Optimisation’ sub-system that reflects on the delivery through data analyses and attempts to optimise the delivery system.

The cost of providing availability through a PSS was expressed as the result of resource consumption in all of these three sub-systems. Further analysis led to the emergence of an additional sub-system that directly impacts on the PSS as an information and knowledge receiver and sender. This so called ‘Governance’ function indirectly contributes to the consumption of resources required for delivering the desired outcome by imposing activities onto any of the three PSS sub-systems as well as by its own activities that can be attributed to the PSS. Table 20 gives examples of quotations that reflect the identification of the identified top level functions.

Figure 22 shows these sub-systems and potential relationships between them. In addition to the functions shown in Table 20, the receiver of the available aircraft, its deployment and operation is summarised in a top level Usage function. The relationships, inputs and outputs shown in Figure 22 only loosely follow the IDEF0 standard in that there are no specific controls or mechanism depicted. Rather, the relationships shown represent *potential* links between the functions within the boundaries of the System of Interest (SOI) (dashed line), of the SOI with the environment in general and with specific elements of the environment, namely Governance and Usage. Table 22 in section 5.3.2 specifies relationships between the five top-level functions in terms of knowledge, information and material flow.

The study focused on functions of Analysis & Optimisation, Administration and Delivery and to a lesser extent Governance within GE Aviation and BAE Systems. Governance is shown as a single process to represent the impact of higher level management of BAE Systems, GE Aviation, the UK MoD, Eurofighter and Netma (see Figure 15). The Governance function was placed outside of the borders of the

Table 20 Exemplar quotes attributed to the top-level functions (*italics added to highlight the motivation for attributing the statements to the respective top-level function*).

Governance	<p>"...or an [availability contract] type question it will come into [BAE Systems]. Say, 'we have got an issue, here is some <i>funding</i>, here is a lot of questions, <i>we like an answer</i> within a certain number of days'." (3778)</p> <p>"...there is no governance at all..." (...)</p> <p>"...ultimately, Eurofighter <i>measuring</i> industry and there are <i>financial penalties</i>..." (3481)</p> <p>"... I am <i>not into the detail of the sort of things</i> [they] are doing but I would run a regular review structure, so I have an <i>oversight</i> of [what they are] doing, what the key issues are, where the <i>threats are and the opportunities</i> are." (4479)</p> <p>"... it's still very <i>strategically</i> important, cause that's important to this site and it's <i>important to our business</i> ..." (4479)</p> <p>"...then for example every six months or so you would have a meeting [with GovOrg, BAE Systems and other organisations]. But that's more of a challenge meeting, a cost reduction challenge [...]. It's <i>not part of operational business</i>." (4479)</p> <p>"...the only way to improve that [customer unit] is to put it in front of [another customer's unit]. In that instance and if we can't do that and the [customer is] desperate for it then there is a route where they will go into [GovOrg] and reference it and we will <i>get the consent from them</i> to move the units around. [...] So <i>it wouldn't satisfy the contract [for the other customer]</i>." (3481)</p> <p>"...nobody has requested this. This has been an internal decision, but it has affected our support level. But rightly or wrongly that's a decision that <i>someone else</i> has made." (3493)</p>
Analysis & Optimisation	<p>"...<i>looking at any new investigation reports</i> that came in, <i>doing the analysis</i> that is supplied to any other team we interface with..."</p> <p>"...you stick it all in a <i>spreadsheet</i>, you <i>do all your charts</i>, you can <i>start to see things</i>, and you get a feel for your equipment, because maybe [...] two or three occurrences of a single fault on your equipment may be nothing, but two or three occurrences on another person's equipment may be a massive issue, depending on the level of failures in general..." (3778)</p> <p>"...<i>collecting in-service data, looking at it, looking for trends</i>..." (4928)</p> <p>"... will have a meeting with the [team leaders] and they'll sit down and say 'these is the <i>issues we're seeing from the suppliers</i>, you're damaging screws, you're doing this, you're doing that'. And then what the [team leaders] do is they go back to their [personnel] and say: 'right, it's been told that this is getting done'. Not casting any blame or anything, just say 'we need to be wary when we're tightening screws up or cleaning screens or [...] scratching them'. Scilly little things like that. It's all just <i>trying to look after the small things</i> so that the <i>big things don't happen</i> really. (4928)</p>

Table 20 (Continued)

Administration	<p>"...the <i>purchase order</i> then will go to our [<i>contracts</i>] department, checked through contracts..."</p> <p>"So once we have received the <i>purchase order</i> ... we put it through our process, ... the <i>pricing, the quoting stage, we then send the quote</i> to [BAE Systems] ..." (6989)</p> <p>"...we have to rise what we <i>call compliance paperwork</i>, which would be [...] <i>check lists</i> to say who the customer is, etc. ..." (7149)</p> <p>"...they are the guys who do all the <i>purchase orders</i> and stuff for any defect reports that are raised. So, when a defect report is raised, it will go back to the supplier, and then there's got to be a <i>repair order</i> raised, and a purchase order to say acceptance, to say it's going to cost you x thousand pounds to repair this unit. 'Do you accept, do you not accept?'" (3778)</p>
Delivery	<p>"...a unit is <i>repaired</i>, so it comes out from the workshop with its own paperwork ... which would tell you exactly what they did with it, it'd also show you which <i>parts have been used in that repair</i>..." (7149)</p> <p>"...the job then will appear on the <i>workshop</i>. So that's when all the contract stuff has been put in place and they are happy it <i>can be worked on</i>. [...] And [the team leader] is tasked with checking the work flow through the team and he knows when contract dates are coming up and all this. So he sees to distributing the work. So he will then say "right, that number needs to be picked up" and then it will <i>come on test</i> and I or one of the others techs will <i>pick it up and work on it</i>." (2596)</p>

SOI and therefore out of the scope of a detailed investigation. The reason for that is the inability of the Administration, Delivery and Analysis & Optimisation functions to take action on the Governance function.

Within Usage the RAF has the ultimate authority to decide how to employ the equipment. Nevertheless, there are opportunities for BAE Systems to influence sub-activities within Usage, these could for access reasons not be considered in detail.

When translating the delivery of MHDD, as shown in Figure 21 into a functional perspective, activities situated within organisations are now assigned to the top-level functions Administration, Delivery and Data Analysis & Optimisation. These activities are listed in Table 21 and no longer relate to particular organisations or locations within an organisation. For example 'Create quote', although being an administrative activity is carried out by repair technicians who are mostly involved in Delivery, repairing and testing the equipment.

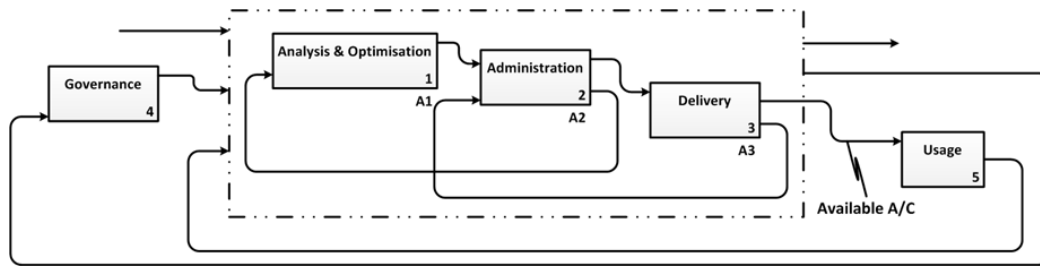


Figure 22 Main functions constituting the PSS for aircraft availability provision, relationships are shown for exposition only.

Of particular interest for the Analysis & Optimisation function, the availability of current and relevant data, as for example the time spent for specific activities differs between the top level functions. Within the Delivery function a GE Aviation process improvement project leader explains: “So when the guys are working on the job the clock is ticking so to speak. That’s all captured and that’s all good data because [...] the clock is on to it. [...] So you know when things are being worked and when they are not.” (7749) By contrast, the specific assignment of working time for Administration functions is not necessarily as clear cut, which is explained by responsibilities “for every customer that requires something repaired [...] externally. So, that’s not just [the Typhoon], it’s [Aircraft 2], it’s [Aircraft 3], it’s [Aircraft 4], [Aircraft 5], everything. So, my time is split between customers, any critical issues that are by day, if [customer X] have an ‘Aircraft on Ground’ in [New York] or wherever, or [the RAF] have an issue with an MHDD. My time is split up randomly throughout the day. [...] I can’t dedicate my day to something, because there will always be something else I need.” While detailed information from the Administration function might not be available, Analysis & Optimisation is indeed more concerned with the modelling of the Delivery function, than the activities undertaken in *all three* functions.

Table 21 Activities within the SOI top level functions

Administration	Delivery	Analysis & Optimisation
Create purchase order	Pack equipment	Create performance report
Release purchase order	Test equipment	Collect data
Create quote	Repair equipment	Analyse data
Create performance report	Transport equipment	Model “Delivery”
Transfer fault report	Create repair report	Create investigation report
Compliance & release documentation (e.g. ITAR)		Create/modify procedures

5.3.2 Relationships among top-level functions

In the previous section the top-level functions of the PSS were identified and described. Information, knowledge and material related relationships between the top-level functions Governance, Analysis & Optimisation, Administration, Delivery and Usage are shown in Table 22. In the leftmost column the sender is indicated while the header row designates the receiver. The grey shaded diagonal represents information, knowledge and material flow within the same function. These would be visualised on a lower level map in IDEF0 if the top-level function is decomposed. The centre of the matrix is formed by the SOI, representing the

Table 22 Information, knowledge and material flow between the main PSS sub systems

To From	Governance	Analysis & optimisation	Administration	Delivery	Usage
Governance		Funding;	Funding; Performance reviews; Price assessment; Priority requests	Equipment;	
Analysis & optimisation	Performance reports; Investigation reports;	Investigation reports;	Procedures; Conversation (personal, emails); Reliability reports;	Procedures; Training;	Recommendations; Procedures
Administration	Performance reports; Invoices and quotations;	Contract interpretation; Conversation (personal, emails);	Contract interpretation; Purchase order; Conversation (personal, emails);	Contract interpretation; IT system (repair orders, part orders)	
Delivery		IT system (Fault reports, repair reports, delivery dates); Conversation (personal, emails);	IT System (Fault reports, repair reports, delivery dates); stock levels	Repair records; Equipment (Sub-modules, Ex-Equip)	Available aircraft; Non-functioning equipment
Usage		Flying hours (IT system)		Fault reports (IT system & form)	Discrepancy log book

links between Analysis & Optimisation, Administration and Delivery. For these functions the information, knowledge and material they exchange with each other as well as Governance and Usage are shown.

Information links, as shown in Table 22 implicitly stand for activities requiring either the creation of the documentation, the physical movement of personnel and activities undertaken as a direct result of information reception. An example for the latter is the interference of the Governance function with Administration and Delivery activities through the prioritisation of repairs following requests from the RAF or other customers. Under normal circumstances the administration levels in BAE Systems and RAF would communicate directly. However, if the RAF or another customer requires prioritisation, a parallel communication route from the RAF to the Administration in BAE Systems via the Governance function is established.

As an example of reporting, the process of reporting from the Administration to Governance is described from the perspective of BAE Systems. The reporting process starts with Eurofighter producing *“their data at the end of each month, which invariably tells us we are failing, and then we produce our data and we have the data challenge on the discrepancy even though we are using the same source data. And we come to the agreement that we were right because we get the more topical information. A lot of it is down to the sentence in what’s in the contract, what’s out of the contract. So without our input to Eurofighter it would look like the suppliers are failing the contract in a lot of occasions. That is simply because the units that aren’t covered by the contract generally have longer repair turnaround times.”* The need for negotiating the assessment of performance metrics was linked to problems with up-to-date information within IT System 1 (see Figure 21). It was also suggested that the automatized generation of reports by Eurofighter would increase that need for personal interaction to achieve agreement between Eurofighter and BAE Systems on the achieved level of performance. As an additional point regarding performance measurement it was highlighted that the RTAT is measured between points in time when the equipment is booked into System 1 at GE Aviation and checked out of that system again as *“ready for collection”*. These dates do however not necessarily reflect the point in time when the equipment *arrived* at the supplier’s site or when it left GE Aviation.

Similar to the Governance functions, the user indirectly and directly impacts on the activities within the PSS, be it through the removal of functioning equipment or fault reports that reveal little about the fault and the operating conditions of the equipment while failing. In both cases activities within the Administration, Delivery and possibly Analysis & Optimisation functions are triggered.

The analysis of field data plays an important role for the Analysis & Optimisation function. Its results can lead into reliability growth improvement programs requiring equipment design modifications, as well as changes to maintenance processes or training. The analyses are carried out in several different sub-groups and each of them having their own focus: “[*That specific Analysis & Optimisation group*] are kind of a bit different in that they are a bit more on doing their own type of thing.” Such different priorities of organisational units, even though in principle they belong to the same top level function are understood to potentially lead to the duplication of activities.

5.4 The ‘relevant’ system model

The relevant system model summarises the findings discussed in the sections 5.2 and 5.3 in a representation that pragmatically follows the IDEF0 standard. This approach was chosen to prevent a diversion of attention from the content of the maps to the exact conformity of the models with the IDEF0 standard. Also, the representation is streamlined for clarity reasons and as such does not include *all* the elements that were discovered and discussed above. In addition, in section 5.4.4 a FRAM map is presented that shows a more detailed view on the processing of an MHDD repair.

5.4.1 Node tree

The IDEF0 standard refers to the node tree as a decomposition of the complete IDEF0 model. The node tree is optional and its format is not specified in the IDEF0 standard (National Institute of Standards and Technology, 1993, pp. 35–36). The node tree shown in Figure 23 depicts the context of this research as ‘Setting’ constituted of Governance and Usage function and the PSS of interest (PSS OI), as described above in section 5.3 “A functional view”. Node references are only used for elements within the PSS OI which is designated as C0. C0, in deviation from

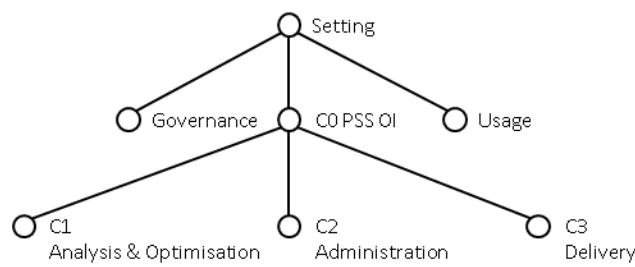


Figure 23 Model node tree.

the IDEF0 standard, stands for the 'CATA'0 level and captures functions that were investigated in this research.

Commonly, nodes depicted in the node tree indicate that the respective function is further detailed in a child diagram. Here, only the 'C0 PSS OI' function shown in Figure 23 is broken down into more detail in the following.

5.4.2 The context map C-0

The IDEF0 standard specifies the representation of the A-0 level (here C-0) as a single box showing only the A0 function. Nevertheless, the C-0 map shows the links between the Governance and Usage functions and the PSS OI. Such representation is chosen to highlight through which channels Governance and Usage impact on the delivery of avionics availability.

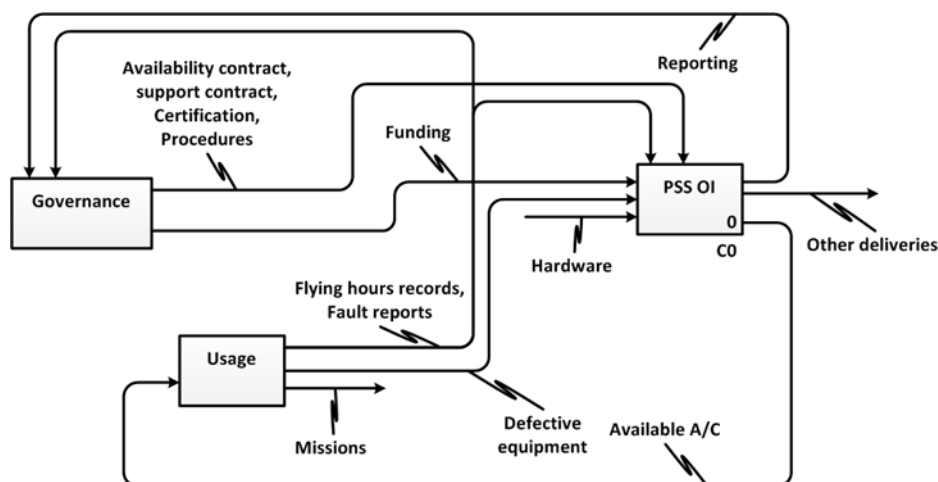


Figure 24 Top level map, C-0 (CATA-0).

In a functional perspective the MHDD can no longer be separated from the 'rest' of the aircraft because the 'Usage' function delivers its output 'Missions' by means of the 'whole' aircraft. Therefore, the delivery of avionics availability as shown in Figure 24 is an integral element of aircraft availability and not represented separately. 'Other deliveries' aggregate the MHDD repairs provided by GE Aviation that are not processed under the support contract agreement with BAE Systems for the UK Typhoon fleet. The 'Usage' function provides enabling inputs and controls such as 'Defective equipment' and 'Fault reports' to the PSS OI. The boundary conditions for the delivery are set by the 'Governance' function through contractual agreements, certification requirements and procedures. Funding provided from Governance enables the PSS OI to operate; in return the PSS OI has to fulfil 'Reporting' obligations. Any material and equipment required by the PSS OI to deliver its outputs is depicted as 'Hardware'. Resources (or 'mechanisms' in IDEF0 terminology), such as test equipment, qualified personnel and electric energy are not shown in Figure 24.

5.4.3 PSS of Interest, C0

The PSS OI, as shown in Figure 25 comprises the three functions 'Analysis & Optimisation', 'Administration' and 'Delivery'. In accordance with the IDEF0 standard the interfaces connecting to C0 in the parent diagram (C-0) are shown as boundary arrows in Figure 25 (National Institute of Standards and Technology, 1993, p. 26). In addition the internal interfaces are specified, these are based on the flow of material and information summarised in Table 22. Information is exchanged through multiple channels that are not specified in terms of the information carrier such as documentation on paper, emails or phone calls, with the exception of IT Systems ('IT Sys'). The reason is that the same contents could be transmitted through any of these, on the actual situation. 'Insights through site visits' provide the Analysis & Optimisation function with knowledge through the individual's tacit knowledge that cannot be transmitted through other information carriers.

Material flow, depicted as 'Hardware' and 'Defective equipment' is limited to the 'Delivery' function where the equipment is physically handled. The 'Delivery' function ultimately fulfils the purpose of the PSS, the delivery of 'Available

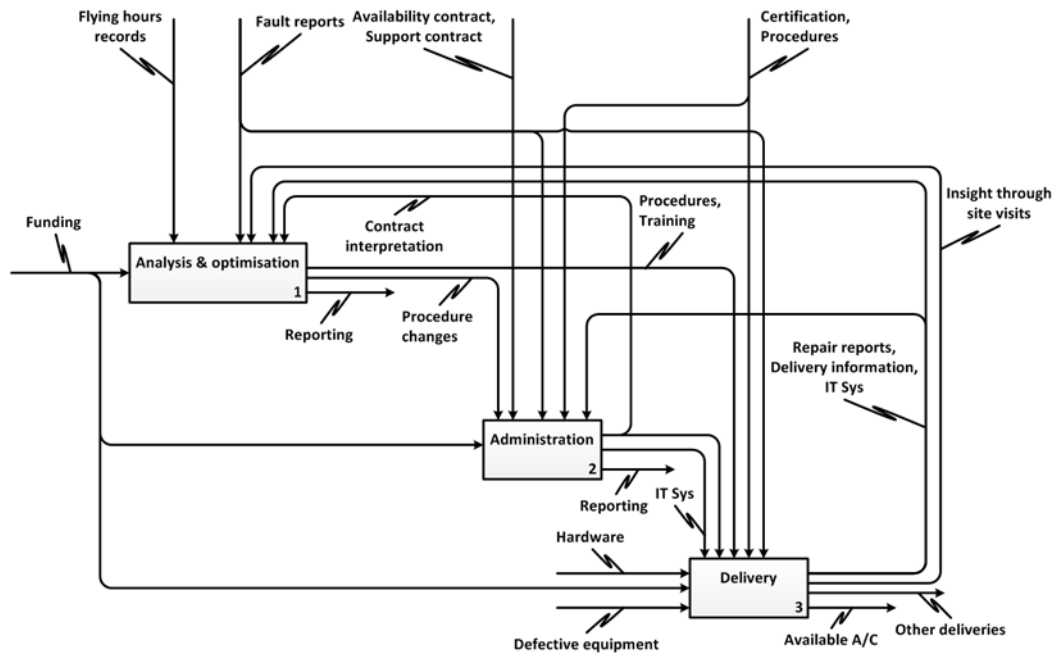


Figure 25 The PSS of Interest (PSS OI), C0 (CATA0).

aircraft', including functioning avionics (and three MHDDs per single seat aircraft).

It can be observed that the three top level functions mutually depend on each other and none of the Administration, Analysis & Optimisation or Delivery function could provide the desired outcome without the others.

5.4.4 FRAM map

A representation based on FRAM is chosen to depict the flow of information and material for an example of a repair process in Figure 26. FRAM diagrams do not have a hierarchy and therefore show processes from different top-level functions in the same diagram which is considered beneficial for understanding *how* the MHDD is made available to the user. In deviation from FRAM, the elements in Figure 26 are a combination of functions, ('Transportation', organisational units, ('BAE In-service support') and locations ('Airbase').

The 'Transportation' function refers to an element of the PSS that has so far not been represented and reflects the difficulty of drawing clear cut boundaries between the PSS OI and the environment.

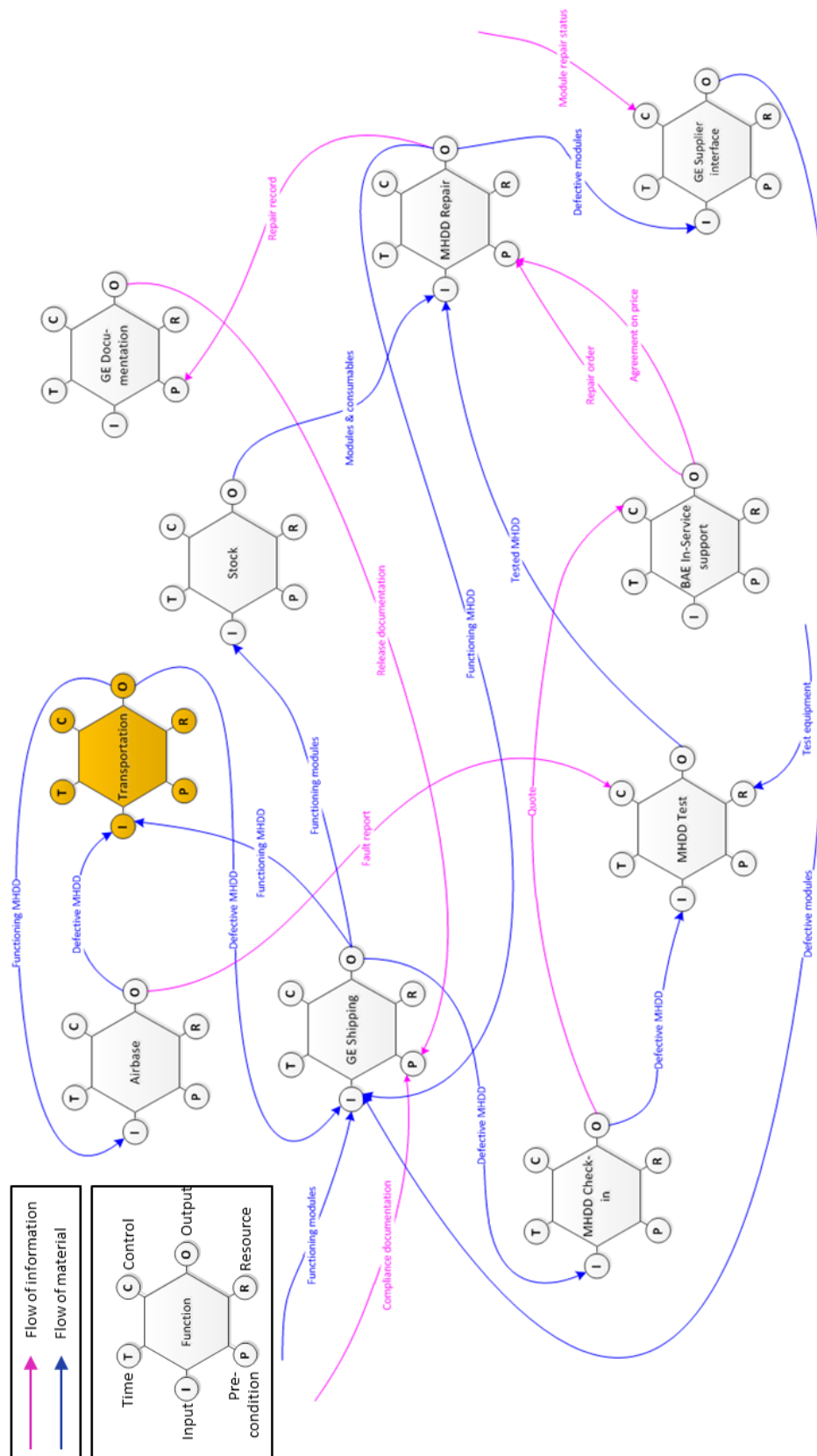


Figure 26 FRAM diagram of MHDD repair processing.

Transportation as a function has to be considered as being within the boundaries of the PSS OI, it is however provided by organisations that are outside the scope of this research. Therefore, Transportation is coloured in Figure 26 to reflect its particular characteristics.

The example shown in Figure 26 is an MHDD repair that requires GE Aviation to issue a quote and reach agreement with the BAE Systems In-service support before a repair order allows the repair to be carried out, such as a 'customer damage'. An NFF would be similar, however the 'MHDD Test' would yield a 'Functioning MHDD' and 'MHDD Repair' would not be needed. Processing the repair starts at the 'Airbase' output that provides a 'Defective MHDD' via the 'Transportation' function to 'GE Shipping' which symbolises the gate into GE Aviation's responsibility. Additionally a 'Fault report' is provided by the 'Airbase' that acts as a control on the 'MHDD Test' once the unit has passed the 'MHDD Check-in' at GE.

One of advantages of the representation shown in Figure 26 is that one can easily see which process (or element) has the most connections and where 'Preconditions' need to be fulfilled before an element can deliver its output. In Figure 26, the 'GE Shipping' element symbolizes the gate into and out of the GE Aviation responsibility. As such, all material goes through GE Shipping and hold ups in the preconditions 'Compliance documentation' and 'Release documentation' can cause a repaired MHDD to remain within the GE Aviation responsibility and lead to failure the meet the contractual RTAT.

5.5 Findings from emerging themes

In the following the themes 'Obsolescence' and 'Knowledge about the contract' are discussed. These two appeared to be particularly important, either because they were explicitly mentioned during the interviews as was the case for 'Obsolescence', or because they were implicitly addressed by several interviewees, as in the case of 'Knowledge about the contract'.

5.5.1 Obsolescence

One of the themes frequently mentioned as a critical challenge to delivering avionics availability is the obsolescence of components. Obsolescence means that

these components are no longer manufactured, and therefore become unavailable (Solomon *et al.*, 2000, p. 707). Long-life technical systems, such as military aircraft, and in particular avionics are affected by obsolescence, *"...[c]ause when we set up a contract it's normally say 'you will supply however many aircraft plus support for a period', it's normally 25 years. Now, when you talk in Avionics and electronic equipment, imagine some 25 years time what electronics will be like. A lot of the Typhoon stuff is quite old. It is designed in 80s and a lot of it hasn't changed that much. So, Cathode ray tube technology and that sort of things, capacitors and all this sort of things. Computers are changing daily, isn't it?"*

For the BAE Systems in-service support discovering that components have gone obsolete can mean that efforts to solve a particular problem with a piece of equipment need to be replicated which is perceived as *"times wasted on obsolescence as well"*. To prevent such work duplication access to a centralised IT system was suggested *"which would state that that item is now obsolete"*. Whether such IT system already exists was unclear.

While the inability to purchase required components significantly affects the in-service delivery of the MHDD through the repair process, its impact is not limited to the repair. This is expressed from the side of BAE Systems as: *"The problems we find and starting to find now on some of this GE kit is supportability in terms of, not so much the world of pure support [...]. So it's 'can GE provide all components for the MHDD?' Just for the building [of the Typhoon], never mind the spares and the 25 years they are on."*

As shown in Figure 27, the supplier, be it GE Aviation or one of their suppliers identifies potential obsolescence or current obsolescence issues. Here, three themes were linked to obsolescence code each of them highlighting different aspects of how obsolescence is dealt with and what it means for those who are involved.

Before any measures for mitigating the obsolescence of components can be taken, the potential obsolescence needs to be *identified* which is a contractual obligation of the supplier. *"And then the supplier has a duty in the contract to notify us if there is an obsolescence and how he plans to mitigate it."* However, only when the supplier and the customer, here GE Aviation and BAE Systems have a shared view on the relevance of the potential issue actions can be taken. Currently, the perception

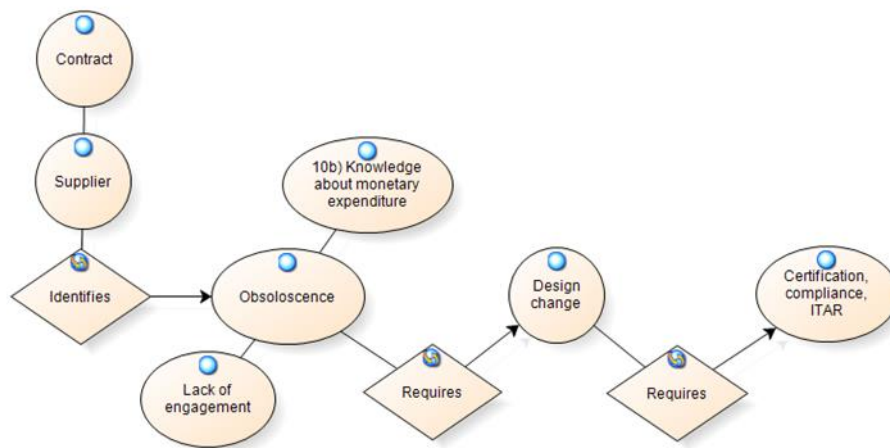


Figure 27 Conceptual model of codes related to 'Obsolescence'.

from the side of GE Aviation is that lessons should be learned from other platforms where *"a whole series of in-service issues [become evident] because the equipment has been neglected, cause we haven't invested in obsolescence, we haven't looked at supportability models. So now there are crises going on which Typhoon is heading towards and we are trying to make people aware of that but that's not the model that people are too engaged on. And that's a time thing. If you talk about it everyone says it's important but then they just get lost into the day job."* This statement exemplifies the link in Figure 27 between 'Obsolescence' and the code 'Lack of engagement'. A further hint of the relationship between BAE System and GE Aviation, might be this statement from BAE Systems on the cost of obsolescence: *"... because the supplier is responsible for the bills of material. [W]e are not bothered what's in it, as long as it meets the spec. But if the bulb goes, and you can't get the bulb it's only then we find out it is actually £ 400 for a bulb"*. This statement points out that BAE Systems only shows interest in the hardware details is once there is a problem. Such position fits the perception from the GE side about a lack of proactive engagement from the BAE Systems' side.

Ways to address obsolescence can be 'last time buys', changing the supplier or the implementation of design changes. While last time buys can mean significant financial commitment, they may avoid procedures required when changes need to be implemented, as expressed from the side of BAE Systems:

"One of the options would be, this component has gone obsolete or will be obsolete by the end of we can't get it anymore, but if you want to fund we will buy up quantities to cover all the production build plus your spares plus a bit more but it will cost you X. And that's the price that we have got to negotiate, or can we share that pain with the supplier, or it might be we just can't get it anymore and we need to qualify something else. [It means] we replace that with that but we will have to requalify that and there will be a cost around that, paperwork [etc.] and it varies from component to component."

In all cases, *"there is a lot of cost potential and we don't know the extent of it, in just getting the equipment built to a standard that it has always been built at. [...] And that adds cost and it's unquantified at the moment. [...] It's a problem, but it's not like I say for an MHDD it's £ 200 000 and we'll know an obsolescence will cost £ 10 000, it's very very difficult to put a figure on it."*

The above statements link obsolescence to the 'Knowledge about monetary expenditure', i.e. how much money needs to be spent to resolve a particular case of obsolescence. It can be summarised that obsolescence events are handled on a single case basis and that the financial commitment may not be known to those who are involved. One of the reasons for this lack of awareness is that while a last time buy might mean a single purchase, the implementation of changes requires multiple processes that can be in-transparent to the individual employee. Changes to the equipment require engineering resources and, depending on the kind of change, have to undergo a formal change process through Eurofighter and NETMA. Changes where *"fit, form and function"* of the equipment remain the same might require less bureaucratic effort. Although, it was pointed out that *"NETMA and Eurofighter say 'you must tell us everything'."* Overall, the change process is seen as *"a huge bureaucracy and [there are] problems just to get a formal change onto a Typhoon, it can take up to 3 years."*

The long life of technical systems, such as military aircraft means that continuous engineering effort are required to sustain these system and to keep them operational even without increasing their capability. Therefore, design activities take part throughout the life time of such systems, they does not stop once the system reaches the in-service stage, as suggested by models such as CADMID (see Figure 2). The solutions to obsolescence issues are highly case dependent and may

require an unknown number of processes. Therefore, knowledge about the costs of obsolescence can be summarised as being vague and case dependent.

5.5.2 Knowledge about the contract(s)

The term ‘contract’ was mentioned by all 16 interviewees in a wide range of contexts. For example in the repair process the contract number is available to the technician but how the repair get processed and whether spare parts are taken from a dedicated or a general stock is determined by a specific job number. So, while the contract itself determines the repair process the technician does not require knowledge about the contract. By contrast, on the administration level *“you have the contract which will tell really what metrics you got to achieve. So that [knowledge about the contract would be] the fundamental or basic you would have to understand. [You would have to understand] what the requirements of the contract are, [and] I spend a lot of time doing that.”* The above statement from GE Aviation can be found similarly in BAE Systems:

“Because whilst we can be on one side saying ‘right, you must do this’ and we wonder if he might have totally different contractual obligations. And more often than not we find that the contractor is very very keen and willing to help us, and on other occasions saying ‘no’ because he is not being paid to do something, so there he is not going to do anything for nothing. And also I need to understand from our contractual point of view, what are we actually contracted to do. Because it is all fine and well saying that ‘I want to do x number [...] of repairs’, if we as a company are only prepared to pay for another”.

From the BAE side one of the *“biggest challenges”* is matching the customer’s requirements with the contractual obligations, which entails understanding of the contract including transportation routes, supplier contracts, and customer contracts. Even though such knowledge was expressed as fundamental to the work, none of the interviewees that were specifically asked had read the contracts. Within BAE Systems knowledge about the contract is filtered through the commercial department that is responsible for the contract details and monitoring while the contract is in place. This information *“then that gets flowed out into the project management community [that] will then [...] manage that contract and ensure it’s met. It will be the project management community that will then issue out the communications. As a recipient of that, so from a support engineering function [...]*

perspective, we will receive that communication [...] that will set [...] what's important for that specific contract."

The day to day work therefore relies on an *"understanding of what the contract says. And if I am honest my view is that contracts are very wordy pieces of paper useful for solicitors and lawyers to argue when something has gone wrong; but not always useful for the operator who is trying to deliver that. So more often it is the case when you work within the constraints of the contract but always trying to deliver what is best for the customer at the end of the day."*

While the quotes above are from interviewees that are involved in delivering the availability of the MHDD for the Typhoon, none of these individuals or the organisational functions they occupy were involved in *establishing* contracts. Rather, the organisational units *"Commercial"* and *"Procurement"* were stated to be responsible for the establishment of contracts with suppliers and customers.

In summary, knowledge about the contract is an essential element of the day to day work of these involved in the PSS delivering avionics availability. In BAE Systems this knowledge is based on filtered information supplied by other organisational units and locally translated into actions relying on agreements between individuals who directly interact. While within GE Aviation it was less clear how the contract knowledge was generated, it was equally important.

5.6 Limitations

The number of interviewees and the sample across the hierarchies of two organisations means that the representativeness for the respective position of each interviewee is difficult to judge. However, the links between interviewees and the exchange of information and material can be captured because there are always at least two sides that are affected by the flow of information or material. So, one side could always confirm or 'modify' the version of the first interviewee, which was facilitated through the use of the IDEF0 maps during the interviews. However, this cross checking only applies between those activities that are carried out by interviewees. It is very difficult to judge which flows, in particular information flows, between activities were missed where only either the sender or the receiver was among the interviewees. Company internal documentation provided by both companies helped to identify such links. Nevertheless, documentation could not

Table 23 Top-level functions identified within the organisations.

	BAE Systems	GE Aviation	RAF	MoD	Other organisations
Governance	o	X		o	o
Analysis & Optimisation	X	X			
Administration	X	X			
Delivery	o	X			o
Usage			o		
X: Interview with personnel in a position within that function;					
o: Function emerged through the analysis, information about the specific function gathered through interviews or unstructured focus group with interviewees in other functions;					
Empty fields show that the respective function could not be attributed to the organisation.					

provide the richness of insights about what these links *mean* in working practice as interviews could.

Table 23 shows how the interviews conducted match with top level functions and organisations depicted in Figure 21. It is evident that the best coverage could be achieved of the Administration and Analysis & Optimisation functions within GE Aviation and BAE Systems. Functions within other organisations were identified through secondary accounts during the interviews or unstructured focus groups, or by means of company documentation.

The researcher's inability to be directly involved by observing activities means that processes that were not within the responsibility of any of the interviewees, did not touch any of the interviewees' activities, or did not seem worth mentioning by the participants could not be identified. In addition, because the interviews were one-off, some with follow-up discussions, the view the interviewees were willing to share with the researcher may be one that is "*cleaned up for public discourse*" (Charmaz, 2000, p. 525). Even though proposed by the researcher, a sustained involvement of the researcher within GE Aviation or BAE Systems, for example for observing day-to-day activities, could not be realised.

5.7 Summary of findings

From the sections above seven key findings are extracted that concern aspects of the delivery of avionics availability by BAE Systems and GE Aviation to the RAF for the example of the Eurofighter Typhoon MHDD. Additionally, as formulated

in the research aim, several representations of the investigated setting were created.

Finding 1: The Availability contract (TAS) and the Support contract overlap in BAE Systems and lead to an organisational split.

- a) GE Aviation delivers MHDD repairs based on defined turnaround times to BAE Systems.
- b) BAE Systems is contracted to deliver aircraft availability to the RAF.

Finding 2: Personnel from GE Aviation and BAE Systems emphasise the importance of knowledge about the equipment usage on the airbase.

Finding 3: The contribution of BAE Systems to the MHDD delivery is administrative.

Finding 4: In GE Aviation multiple routes co-exist to deliver MHDD repairs.

Finding 5: The relationship between BAE Systems and GE Aviation is perceived as transactional.

Finding 6: Resolving obsolescence requires continuous involvement of all parties and is hard to quantify in monetary values.

Finding 7: Contract knowledge is important but based on the interpretation of filtered information, requiring local negotiation between individuals of different organisations.

Representations of the PSS OI:

- Map showing the material and information flow between organisations.
- Maps representing a functional view on the delivery of avionics availability.
 - The PSS OI delivers the desired outcome, a ‘Governance’ function and a ‘Usage’ function influence how the PSS OI works.
 - The PSS OI comprises ‘Analysis & Optimisation’, ‘Administration’ and ‘Delivery’ functions.
- A map representing a specific scenario on how an MHDD repair is processed.

6 Concluding remarks

There are distinct key findings for BAE Systems and GE Aviation. As for BAE Systems, the variety of contracts and roles reflected in their organisational structure stands out. The resulting segmentation does affect the relationship with GE Aviation and compounds communication between both parties. While variety also plays a role within GE Aviation, from the researcher's viewpoint this appeared to be less confusing than the situation in BAE Systems. GE Aviation's situation can be characterised by a tension between a relationship with their customer which is 'typical' for PSS, where both share a common interest and work towards its achievement together. This is shown by GE Aviation depending on inputs from the customer (BAE Systems and the RAF) to provide their deliverable and resources provided by the customer, and a *transactional* relationship that limits them to meet their RTAT and inhibits further engagement.

It can be observed, maybe counter-intuitively, that neither the organisational nor the functional perspective show 'avionics availability' as an output of an individual process. Instead, the meaning of avionics availability depends on the perspective of the actor (organisation, group, individual). GE Aviation for example delivers 'available MHDD' at that moment they declare a repaired unit "*ready for collection*" while meeting their RTAT. As for BAE Systems, there is no dedicated metric for avionics availability; rather the availability of the aircraft fleet is measured.

Comparing the representations of the findings, from a 'look and feel' the map based on FRAM seems to offer a more comprehensible representation than following the IDEF0 diagrams. A combination of both can be useful, by using the IDEF0 maps as a 'whole' system representation and the FRAM map to depict specific scenarios where only the relevant elements and links are displayed.

PART V: DISCUSSION

*You Can Do it Your Own Way
If It's Done Just How I Say*

Metallica (1988)

This part compares findings from the empirical study to previous works from the literature on PSS in general, cost estimation, and cost modelling for PSS and points out differences and similarities.

1 PSS-related findings

Most finding presented in Part IV, section 5 relate to *how* the MHDD is delivered through multiple functions within BAE Systems, GE Aviation and other organisations. These are visualised in maps loosely following the IDEF0 standard and a FRAM diagram. Furthermore, the findings comprise the importance of information flow and contractual knowledge. In the following these findings are compared the literature on PSS.

1.1 *The structure of PSS*

With regards to the specific findings on what constitutes the PSS of interest, Mills *et al.* (2013) highlight the complexities of multi-organisational service provision. Following Perrow (1984, p. 78) complexity is a result of interactions between system elements being “*of unfamiliar sequences, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible.*” In carrying out this research similar challenges arose. In particular, complexity was encountered

in the process of identifying suitable interviewees and the identification of organisational, as well as functional elements and links between them. This is in line with the observations by Mills *et al.* (2013). Furthermore, parallels to the findings presented in this work and the study conducted by Mills *et al.* can be drawn with relation to the organisational structures of the availability provider, exhibiting Back Offices as well as facilities and Front Offices close to the user. From a functional perspective, the Governance function identified in this research has its counterpart in a generic “Governance” organisation that “determine how the rest of the organization operates” while having “little direct interaction with operations, but strongly influence its ability to function” (Mills *et al.*, 2013, p. 171).

Across both organisations, BAE Systems and GE Aviation, it has become evident that there is not *one* delivery that can be easily considered separately from others. There are always shared resources and activities that cannot immediately be attributed to a single contract or delivery. However, the availability of data about specific functions varies significantly between the Delivery, the Administration



Figure 28 Blurred boundaries around the System of Interest (Background image copyright: BAE Systems).

and the Analysis & Optimisation functions identified in this work. Unlike for example Sharma *et al.* (2011), the author does not recommend a database that captures “*every action*” involved in providing functioning equipment for the following reasons: The case-specific complexities described above stand in the way, and in general the state of knowing ‘every action’ simply cannot be achieved in socio-technical systems (Hollnagel, 2012). Instead, more attention should be paid to “*process opaqueness*” (George, 2010). In the presented empirical study, process opaqueness is appropriate to describe the emergence of insights about the delivery of avionics availability and the inability to achieve complete knowledge within the SOI and about the links of the SOI with the environment. For example, the Governance and the Usage functions being placed outside the SOI are linked through inputs and outputs to SOI elements. For the purpose of seeking agreement about *how* avionics availability is delivered through the PSS, both functions are considered *important* to be represented but not *transparent* enough to potentially take action on them. Hence, the boundaries of the system are defined by the willingness and ability to take action. Incomplete knowledge expressed as ‘opaqueness’ with respect to the SOI, can be interpreted as ‘blurred’ with respect to the system boundaries (see Figure 28).

Removing the hard distinction between the SOI and the environment can direct efforts towards increasing the transparency of processes within these blurred boundaries if they are recognised to have significant impact on the SOI.

1.2 Comparison to key characteristics of PSS

In the following other key characteristics of PSS, as identified by Phumbua and Tjahjono (2012) are discussed:

- Combination of transactional-based and service-based processes.
This finding can be confirmed, within BAE Systems being an aircraft manufacturer (and seller) and the availability provider for RAF. Also within the relationship between GE Aviation and BAE Systems both types of processes were identified. While repairs under the Support Contract rely on very streamlined processes, customer damage repairs require transactional processes.

- Facilities close to the customer.

For BAE Systems, as availability provider it is found that there are On-Base activities and facilities, among them AWS. GE Aviation however has no facilities with their customer BAE Systems or with the RAF.

- Operational performance measures.

Between BAE Systems and RAF aircraft availability metrics are in place. By contrast, GE Aviation provides a specified RTAT under the Support Contract, and a repair time which is based on 'the best of their abilities' when it comes to customer damage repairs.

- Technology to improve visibility.

Visibility, in particular for GE Aviation is an issue which was partly attributed to the utilisation of different IT Systems by RAF and GE Aviation. However, lacking communication between the On-Base activities and GE Aviation, irrespective of IT solutions was considered at least equally important. First-hand information about the usage of the equipment was considered important for GE Aviation as well as BAE Systems personnel.

- Relationships governed by product availability and performance.

It was recognised that the Support Contract between BAE Systems and GE Aviation does not necessarily support the availability commitments BAE Systems has to the RAF. Therefore, while performance, in terms of RTAT mattered for the relationship between both organisations, availability of the aircraft was not the main concern for GE Aviation. This situation is comparable to a case in which the service provider has traditional contracts in place with their suppliers (Datta and Roy, 2011).

- Failing equipment.

During the investigation the failure rate of the product was never problematized as the single critical aspect for successful delivery. Rather, organisational issues, communication and administrative workload, such as compliance documentation were raised. These observations are in strong contrast to reliability engineering approaches to availability-based contracts which focus on product-inherent characteristics such as failure rates (Ntuen and Moore, 1986; Sandborn, 2013). Additionally, damages caused by equipment mishandling and NFF were identified as major factors impacting on successful delivery. This aspect is overlooked even in

the reliability literature. Smith (2004, p. 420) points out that an MTBF usually captures only confirmed failures – not all the unscheduled removals. For this reason, using such a metric for an availability-based contract has to be considered inadequate.

In summary, several of the characteristics of PSS as identified by Phumbua and Tjahjono (2012) can also be observed in the delivery of MHDDs, in particular when it comes to relationships between organisations.

1.3 *Relationships between availability provider and supplier*

The challenge of integrating the manufacturing and in-service support identified by Johnstone *et al.* (2009) shows similarities to the situation BAE Systems faced in this study. While these authors stress the importance for such integration with respect to the customer's experience of the service provision, here the impact on the PSS itself is highlighted. From the perspective of GE Aviation organisational fragmentation within BAE Systems compounds an integrated view on the equipment's performance and consequently handicaps the implementation of improvements, be them process or product related. It also shows how the distinction between a PSS 'supply chain' and 'enterprise' translates into reality, an aspect highlighted as lacking in the field of PSS research (Mont and Tukker, 2006). While the concept of enterprise requires a "*common purpose*", a supply chain is characterised by the flow of products or services between independent organisations (Mills *et al.*, 2013). In the presented case, the way the support contract between BAE Systems and GE Aviation is implemented denies the *common purpose*, and the relationships between both organisations reflect supply chain rather than enterprise characteristics. Hence, a service provider's organisational structure affects both sides of the delivery chain, the customer and the provider's supplier. Lockett *et al.* (2011) observe a phenomenon where a service provider changes internal processes towards the customer – similar to BAE Systems' On-Base engagement – with little changes on the supplier facing parts of the organisation. The authors report that the supplier in their case study expressed frustration about the service provider's lack of openness to proposals. This finding is consistent with statements from GE Aviation about their ability to influence the delivery to the RAF.

Finally, another aspect concerns the interdependencies within the service supply chain where the customer provides inputs to the service supplier who in turn provides inputs to the supplier, and the reverse flow from the supplier through the provider to the customer (Maull *et al.*, 2013). With reference to the presented case study, the flow of material and information between GE Aviation, BAE Systems and RAF (see Figure 21) shows that the supplier requires customer inputs to deliver its own output, and to meet its performance targets.

2 Cost estimation related findings

In general, cost modelling studies in PSS or maintenance rely on *given* cost figures (Early *et al.*, 2012; Jazouli and Sandborn, 2010; Lanza and Ruhl, 2009; Roskam, 1990). By contrast, this work contributes to costing PSS, through attributing monetary value to cost objects and by identifying and representing the relevant system. This approach is comparable to ABC, where a process model builds the foundation for the identification of cost drivers and the attribution of monetary value to activities (see for example Schulze *et al.*, 2012). Kimita *et al.* (2009) propose a cost simulation based on ABC for service design, however no application of ABC to an existing PSS delivering advanced services is known to the author.

2.1 Cost estimation for service

When comparing the findings of this research to the literature the specific context and purpose of the study needs to be considered carefully. In particular when it comes to ‘service costs’ multiple meanings can easily cause confusion, and cost estimation for services is usually not cost estimation for advanced service. For example, Garber (2007) when discussing service sector cost control addresses services such as marketing, travelling or legal ‘services’. On the other side, product related services could be identified with servicing events such as repair interventions. A common assumption is that repair interventions are a result of physical failures of the equipment and accordingly the number of repairs depends on the number of equipment failures (Huang *et al.*, 2011; Jazouli and Sandborn, 2011; Lanza and Ruhl, 2009; Scanff *et al.*, 2007). For the present case this would mean that the removal of the equipment from the aircraft on the airbase would always lead to a repair at GE Aviation. The cost calculated in the references above refer to the maintenance intervention on the high level machine, or aircraft and do not seem to consider the effort required for the repair of the sub-system, which

would be the MHDD is this study. Similarly, when availability is identified with reliability and maintainability these product inherent characteristics directly determine the number of repairs, the repair time and the repair costs (Sandborn, 2013; Kumar *et al.*, 2007). A revealing list of the assumptions that may underlie the relationships between a technical system's availability and the associated costs is provided by Ntuen and Moore (1986, p. 348) who admit that these assumptions may physically be unrealistic, but useful for facilitating mathematical analysis:

- *“System failure cost is proportional to the system failure rate.*
- *System failure cost is proportional to the repair rate.*
- *A penalty cost for system unavailability is given by some known function.*
- *Each failure incurs a fixed failure penalty cost.*
- *Actual repair expenses are estimable from the type of required action.*
- *Capital costs of replacement are known.*
- *A continuous cost per time unit is assigned to maintenance.*
- *For a system that operates and fails in unpredictable manner, the system availability is stochastic; hence the cost model is also stochastic.*
- *Costs associated with specific preventive maintenance actions are known.”*

The findings from this research emphasise that such assumptions are inadequate in the investigated context. For example, NFF and customer damage classified repairs fall outside reliability-based reasoning but still require the same (or more) activities, as do confirmed physical failures.

Other authors, such as Nowicki *et al.* (2008) associate the availability of a technical system to the availability of spares. The findings in this study show that the availability of spares did matter at two positions in the delivery of avionics availability. One is on the airbase having an MHDD available when needed, and the second, within GE Aviation, is the availability of sub-modules for the MHDD repair. However, it has also been shown that more conditions need to be fulfilled to turn around an MHDD, such as meaningful repair reports and release paperwork including ITAR clearances. While not investigated in detail in this work, maintenance and reporting practices on the airbase can significantly influence the availability of avionics equipment (Blackwell and Hausner, 1999, p. 276). In the work of Löfstrand *et al.* (2012) maintenance contributes to the delivery of availability through a service support system comprising maintenance

procedures, maintenance resources and maintenance strategy. Compared to this research, Löfstrand *et al.*, 2012 use generic processes and are not concerned with maintenance or repair practices. Also, functions other than those where the equipment is physically manipulated are not considered. Transferred to the findings in this work such an approach would mean that the 'Administration' and 'Analysis & Optimisation' are neglected and costs are exclusively and directly attributed to the 'Delivery' function.

2.2 Structuring service delivery for cost estimation

A generic cost modelling process is proposed by Datta and Roy (2010, pp. 150–152) for availability contracts. The authors focus on information sources and highlight the importance of experienced staff to contribute to the cost model. However, there is no mention of a *representation* of how the advanced service shall be delivered. Instead, a Service Breakdown Structure (SBS) is described as a list that contains 'all' tasks and activities that are required to deliver the desired outcome. Huang *et al.* (2012, p. 10) point out that the creation of an SBS requires "*all the costs incurred during the lifecycle of a service*", including "*all the factors affecting the final service cost [...], such as how often the aeroplane requires maintenance check; what the weather condition is on the plane's working day; has the pilot had enough experience of controlling the plane correctly and safely; what the relationship between flying mileage and plane's lifespan is?*" From a representation viewpoint, a breakdown is hierarchically structured which means that the constituting elements link only to a next higher level, neglecting functional links, or material and information flow across categories. In addition, the SBS requires the costs of services to be *known* upfront. The summation of the individual cost elements yields the overall costs for a service to be delivered. Such an approach is similar to the calculation of 'whole life service costs' capability delivered through services and assets as proposed by Early *et al.* (2012, p. 716).

While the challenge of creating the SBS is recognised, it is attributed to the availability of data and not the identification of 'all factors' that affect the service delivery. Similarly, the achievement of a "well defined problem" as initial step for service cost estimation is not further explored as an area that needs further attention by Datta and Roy (2010, p. 149). Instead, focus is placed on the techniques applied once the problem is defined. Here neither knowledge about 'all

factors' affecting the service delivery, nor the problem definition is taken for granted. As such, this work is distinctly different from other studies in the field of cost engineering.

2.3 *Obsolescence & multiple deliveries*

The literature on PSS identifies obsolescence as one of the challenges a service provider is faced with (Meier *et al.*, 2010a, p. 614). In the investigated setting both, the provider and the supplier had concerns about obsolescence. Romero Rojo *et al.* (2012) propose a framework and conclude that the approach they promote can accurately predict the costs of solving obsolescence issues. Implicitly Romero Rojo *et al.* make the assumption that 'the solution of an obsolescence issue' can be treated as if it was an observable cost object independent of the specific context to which cost can directly be attributed to. However, the results from the present research suggest that obsolescence solutions should not be treated and quantified in such way. In particular when the solution of obsolescence requires redesign and requalification of equipment the context of the specific case plays a crucial role. One of the interviewees pointed out that it *"could be £ 100 to 150k to get a unit to requalification. That either passes or fails. One in 10 times there is a failure. So, somebody would say, there you go, it is £ 15 000 risk money for doing that. [But it] doesn't work like that, because it either passes, nine times out of ten [and then] I don't need that £ 15k, or it fails [and then] 15k ain't enough."*

One of the significant findings in this study that challenges a cost modeller is that GE Aviation provides multiple outputs in parallel that interfere with each other. Such concurrency has also been observed by Maull *et al.* (2013, p. 11) in service delivery. For production systems multiple deliveries are addressed for example by Emblemståg (2003). However, to the best of the author's knowledge, multiple deliveries are not taken into account by the literature on PSS costing and cost estimation. This situation reflects the findings by Settanni *et al.* (2014) that cost estimation approaches for availability contracts are not equipped to handle multiple concurrent offerings.

3 **Contribution of findings from this work**

Fundamentally, the premise for this work, as part of the CATA project, differs from the common approaches to estimating the cost of PSS in the assumption

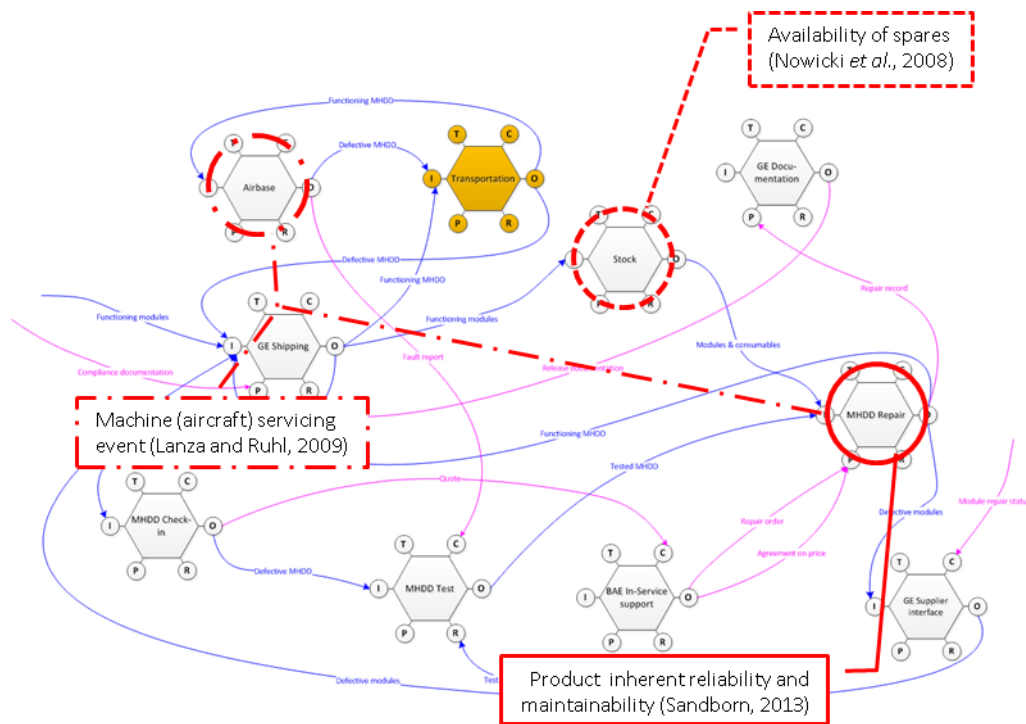


Figure 29 The focus of selected references and where they can be placed in relation to this work.

about ‘known costs’. The aim of CATA is to model the delivery system, i.e. the PSS first, and *then* attribute monetary value to the elements and links in that PSS model. As such, one of the main difference to other studies in the field of cost modelling for PSS, is that this work does not present monetary quantities. Instead, the contribution of this work to the CATA project is that it allows placing the work of others in a context, and relating them to each other. For example, travelling of personnel to the airbase, as a ‘service’, can be placed in Figure 25 as a purposeful activity to gain ‘insights through sight visits’. In this way monetary value associated to travelling would not only be understood as a spending category but as a contribution to the successful delivery of avionics availability. In the same way it can be shown how aircraft repair (or servicing) interventions and product inherent characteristics relate to other processes within a PSS. Figure 29 shows where the results of other studies can be placed in the context of the investigated PSS.

In addition to providing context for previous studies, the representation of an operational PSS can provide context for the concepts of price, expenditure and

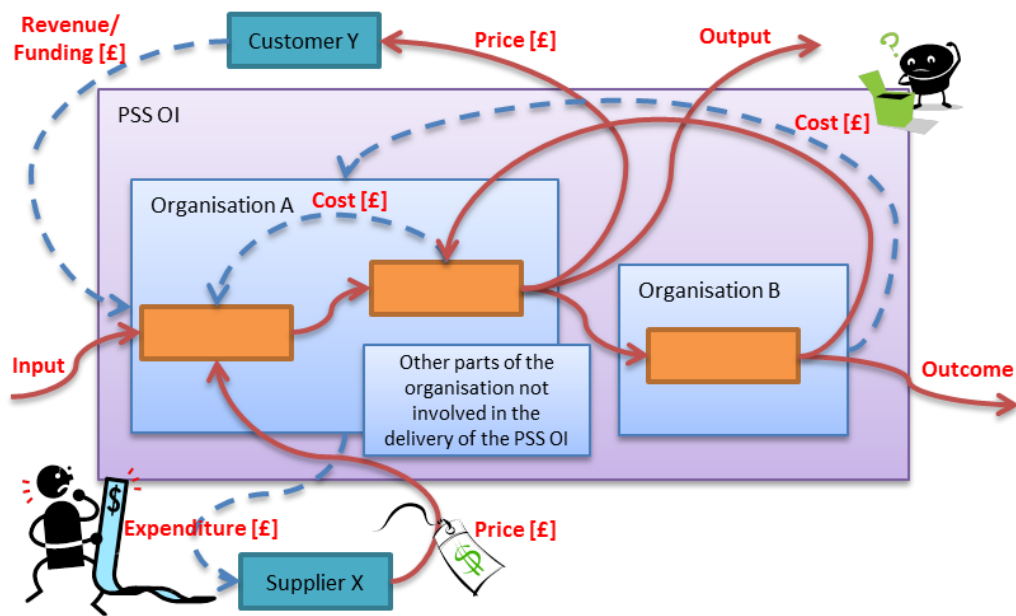


Figure 30 Key concepts and their relationships.

costs. Figure 30 shows a simplified PSS comprising processes of two organisations ('Organisation A' and 'Organisation B'), delivering an 'outcome' to a customer who is not shown here. Material (or service) flows are depicted in solid red arrows, for example inputs and outputs. Material or service flows are represented with a 'price' tag which exhibit a corresponding flow ('revenue/funding' or 'expenditure', shown as blue dashed arrows) in monetary units. These two flows together represent a *transactional* relationship between the material or service provider and the respective customer. An example is the relationship between 'Organisation A' and 'Supplier X'. 'Organisation A' requires an input for one of the processes involved in the PSS, is charged a 'price', and has 'expenditure', i.e. an outflow of money to complete the transaction with the 'Supplier X'.

Within the PSS OI the exchange of material and services is not accompanied by a monetary transaction. Rather, the monetary value of transactions, 'costs', needs to be worked out. In the example in Figure 30, processes from 'Organisation A' provide multiple outputs, one of which is required by 'Organisation B' and as such contributes to the delivery of the desired outcome. At the same time 'Organisation B' provides material or services to enable 'Organisation A' to deliver its outputs. However, because no monetary transaction is involved with each delivery between the two organisations, the monetary value of these deliveries

needs to be *attributed* to them. Only by costing the PSS internal transactions the ‘costs’ of delivering the ‘outcome’ can be determined. Multiple deliveries and organisation-internal splits where parts of the organisation are not involved in the PSS delivery complicate the attribution of monetary value to individual cost objects, be them activities or outputs.

In settings where a PSS reflects the definition of an “enterprise” as a “*system of interconnected and interdependent activities undertaken by a diverse network of stakeholders for the achievement of a common significant purpose*” (Purchase *et al.*, 2011b, p. 18) transactional relationships are not preferred. This work highlights that the exchange of material and services with a PSS are not ‘price tagged’ and that the costs of the delivered outcome cannot be observed by summing up ‘expenditures’. As Settanni *et al.* (2014) point out the cost of providing an advanced service, for example availability, through a PSS requires a formulation of cost assessment as a problem of attributing the monetary value of resources to the activities carried out for achieving the desired outcome. This is a major departure from most cost modelling approaches that regard performance (for example, availability) and cost as properties designed into a product.

PART VI: CONCLUSIONS

Individuals and interactions over processes and tools

Working software over comprehensive documentation

Customer collaboration over contract negotiation

Responding to change over following a plan

Values of the Agile software development manifesto (Beck *et al.*, 2001)

The characteristics of PSS, fluid boundaries between provider and customer, the need to respond to challenges at hand, such as obsolescence seem to offer potential for engineering firms to learn from other fields. In this work the relevance of the social sciences and accident investigation for a methodologically sound approach to qualitative modelling of PSS has been highlighted, other disciplines, such as software development may contribute to support the implementation of practices appropriate for the characteristics of PSS.

This section summarises how the research described in this thesis meets the aim and objectives stated in the introduction. Additionally, the author reflects on the research approach and limitations of the research. Finally, future work is outlined.

1 Research aim

The aim of this work, to provide an approach to integrate social and technical aspects in the representation of *an existing PSS* as a foundation for costing advanced services has been achieved by attaining the objectives outlined below.

1. To identify how to conceptually integrate products and services.
Through the literature, the flow of information, knowledge and material between activities were identified as a common ground of products and services.
2. To identify characteristics of PSS as socio-technical systems.
It is a characteristic of advanced services delivered by socio-technical PSS that outcomes cannot be traced back through direct cause and effect relationships. Rather, outcomes have to be considered as emergent properties that can only be explained through a holistic system analysis. However, complete knowledge cannot be attained in socio-technical systems. These characteristics of socio-technical systems, underline the need to focus on the *defensibility* of a model rather than its assumed comprehensiveness and closeness to 'reality'.
3. To outline a suitable methodological approach to investigate and represent the characteristics of PSS as a socio-technical system.
Ways of knowing about social phenomena and methodological concepts are identified through the discussion of literature including the social sciences. The proposed methodology follows a selection of philosophical foundation, research types, research strategy, methods for data collection and methods for data analysis. To reflect the social aspects of PSS, qualitative data collected from interviews and documentation were considered appropriate in the given context. Process mapping, using the IDEF0 standard and diagrams following the FRAM were identified as suitable methods for representing the delivery of avionics availability. The methodology discussed and methodological approach followed represent a major move away from most of the literature on cost modelling which tends to focus on the quantitative analysis of quantitative product-related data.
4. To apply the outlined approach for the collection and analysis of qualitative data to an existing PSS that delivers avionics availability to identify:
 - a. The *relevant* system elements;
Organisational units, activities, locations and functions were identified as relevant system elements.

- b. The relationships between the elements;
Relationships between the relevant system elements in terms of documentation, IT systems, material exchange and personnel moving between locations were identified.
 - c. The system boundaries;
The system boundaries were found to be blurred due to the overlap of processes and activities that contribute to the delivery of avionics availability and other outcomes. Hence, it is suggested to distinguish between what is 'inside' and what is outside of the SOI depending on the ability to take action on the elements or links identified
5. To represent the PSS delivering avionics availability in a qualitative model that can be used as a foundation for costing advanced services.
This objective was achieved through multiple maps which loosely follow the IDEF0 standard and a FRAM diagram. Three perspectives were shown: an organisation-centred view, a functional view, and a specific scenario blending functional and organisational viewpoints in the FRAM diagram.

2 Contribution & significance

The contribution of this work to the existing body of knowledge is twofold in terms of defining "*what is a PSS*", as well as providing an approach that enables practitioners and researchers to answer the question "*How to know about PSS?*":

1. To demonstrate that the delivery of avionics availability through a PSS has organisational, contractual and functional facets that overlap and influence each other.
2. To outline an approach that takes into account the socio-technical character of PSS to investigate social phenomena within PSS. As such this work structures and clarifies methodological aspects for how to gain knowledge about PSS, and how to analyse the collected data.

The data collected and analysed about the delivery of an exemplar piece of avionics equipment, the MHDD for the Eurofighter Typhoon, has contributed to understanding which functions are involved in the delivery of avionics availability, including the flow of information, documentation and material. While organisational elements, such as groups and departments were always visible

throughout the research, the identification of the three top level functions, Administration, Delivery and Analysis & Optimisation only emerged during the data collection and analysis. Through both, the functional and the organisational perspectives, ‘avionics availability’ could not directly be observed as a singular output of a specific process, nor could it be traced back to a single element or function. Instead, it was found that it was more consistent to regard avionics availability as an emergent property of the whole PSS. Transferring the findings and the representation of the PSS under investigation in this work to other contexts is not immediately envisaged. By contrast, the methodological approach, ‘how to know about PSS’ and the representation techniques chosen are considered suitable for other contexts. Examples in the literature show the application of similar approaches in other contexts that include different settings or life cycle phases, such as PSS design (Evans *et al.*, 2007). The implications for future work is, that an advanced service, such as availability provision can neither be understood nor actively influenced without analysing the PSS delivering that service **as a system**.

As such this research is distinctly different to previous works in cost modelling that:

- Focus entirely on knowledge about the product, missing on the ‘social’ side of the ‘socio-technical system’.

This work has shown that the technical system is embedded in processes and activities that are shaped through social interactions.

- Collect qualitative data to gain additional insight, but make the assumption that potentially complicated cost objects can be taken in isolation and a costs can be directly associated to them.

The findings presented in this thesis show that the outcome delivered by a PSS is the result of interactions between multiple activities and processes that deliver different outcomes in parallel.

3 Implications

Understanding a PSS as a system is particularly important for supporting meaningful cost modelling. Especially in aerospace, a recent critique has highlighted the need for *controlling* program costs rather than making “*futile*” attempts to predicting them (Keller *et al.*, 2014, p. 350). Issues such as multiple

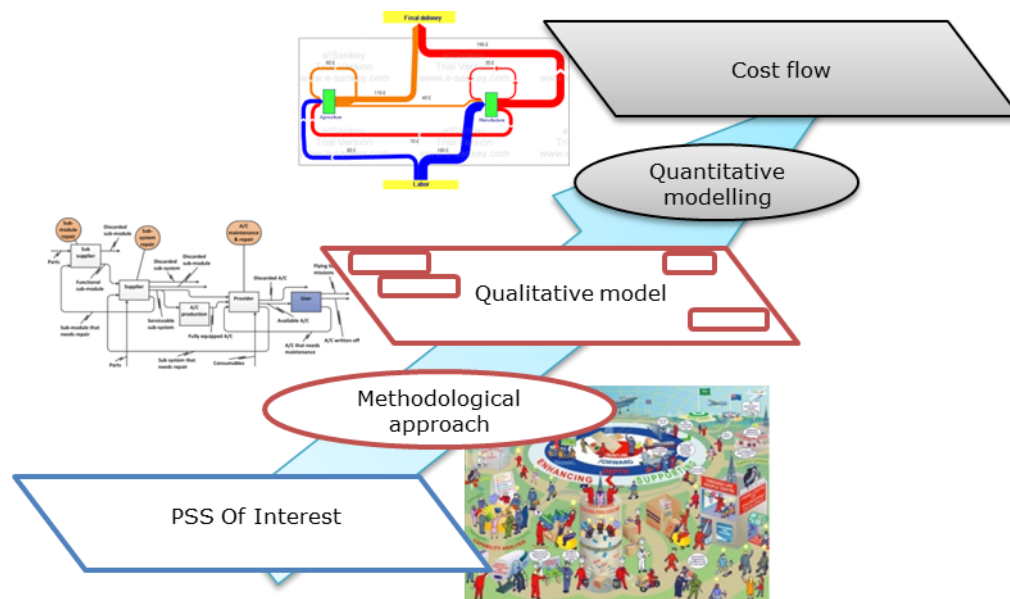


Figure 32 Staged cost modelling approach based on a methodological approach to create a qualitative model, as proposed by the CATA research.

understanding relationships between budgets cuts and capability is an important premise to avoid the death spiral of increased unit prices through reduced order volumes (Chinn, 2013). Through the visualisation of relevant elements of a delivery system, such as a PSS and the relationships between these elements, the qualitative model of a PSS can integrate informed decision making about cost as well as business processes.

4 Research limitations

The limitations of this research are set through its scope (see Part I, section 4), and the limitations of the empirical study (Part IV, section 5.6). The scope limits the work to the specific case of the delivery of the Eurofighter Typhoon MHDD to the UK RAF by GE Aviation and BAE Systems as governed by the Eurofighter support contract and the TAS between summer 2011 and January 2014. The conclusions that are drawn from the empirical study refer only to the case investigated. Nevertheless, as shown in Part V findings from this work exhibit similarities with other works presented in the literature. This demonstrates that certain aspects, for example the challenges of operating different contracts in parallel, may be transferable to other settings, although the context needs to be considered. Similarly, while the methodological approach proposed was

demonstrated for the specific case only, it is assumed that the methodology is appropriate also in settings that for example include design and manufacturing activities.

5 Author's reflections on the research approach

The direction this work has taken was hard to foresee in its beginning in summer 2011. In particular the strong influence of the social sciences was neither planned nor predefined. The author's experience in aircraft and avionics maintenance, and his education as an aerospace and aircraft design engineer made a contribution to the CATA project focusing on the technical system probably more likely than what resulted in this work. Several aspects contributed to the research taking such course:

1. The author's experience in aircraft maintenance where in practice focus is placed on the technical system and limited attention given to the condition of humans;
2. The limited availability of data related to the MHDD at the beginning of the research;
3. The limited overview and a lack of documentation of how BAE Systems delivers the availability of the Typhoon through the TAS contract;
4. Limited understanding and lack of documentation of the Eurofighter support arrangements.

The author's past experience is independent of the CATA research, and can therefore be considered as an underlying tendency towards the importance of humans in socio-technical systems and contributed to the willingness to further investigate the importance of the human elements of a socio-technical system. By contrast points 2 to 4 are specific to the situation at the beginning of the research. The author's struggle to *understand* what was going on turned out to be a fair reflection of the numerous links and processes involved in the delivery of the MHDD availability. It is the author's view that these multiple links and processes led the collaborators from all collaborating organisations frequently talk about the "*enormous complexity*" involved. Such view is consistent with Soft Systems Methodology (SSM) where 'the world' is seen as messy and complex, and

therefore it is necessary to construct a defensible representation of the phenomenon of interest (Checkland and Scholes, 1999; Wilson, 2001).

Only through the course of the research that went from a focus on “*technological knowledge*” (Bohn, 1994) to knowledge assessment and maturity (Johansson *et al.*, 2011), the researcher realised that the very formulation of the problem was needed. The literature on accident investigation (Vaughan, 1997; Snook, 2002; Dekker, 2006) provided the intellectual bridge between engineering and the social sciences that was required for this work to remain robust while crossing the boundaries of several disciplines. In the researcher’s opinion, the access restrictions that meant the researcher could not gain first-hand insights into how availability was delivered, led to a much more social theory and methodology centred work than is usual in engineering. From a researcher’s perspective this situation posed a great challenge and opportunity at the same time. Opportunities included asking fundamental questions, such as “how can we know about the world”, challenging was finding reasonable answers and expressing them in a humble and comprehensible way. For the researcher it is difficult to judge how consistent the philosophical foundations selected were transferred into methodical practices and ultimately the findings.

Further challenges were encountered during the data analysis. The amount of text from transcripts and the potentially infinite number of codes confirmed statements from the literature, i.e. that qualitative data analysis can easily overwhelm the researcher. Using the maps as deliverables helped to structure the themes and focus on findings relevant to the representation of the investigated setting. Overall, the richness of the data and the stories told by interviewees provided a lively picture of the situation that contained enriching and exciting insights.

6 Further work

One of the results presented in this work is a qualitative model of the PSS OI delivering avionics availability. Proposed future work includes the technical implementation of the qualitative model into a quantitative PSS and cost model. Figure 33 shows a potential combination of different software tools to support the integration of multiple analytical approaches. The structure of the PSS OI is provided by the qualitative model in the format of an IDEF0 representation or a

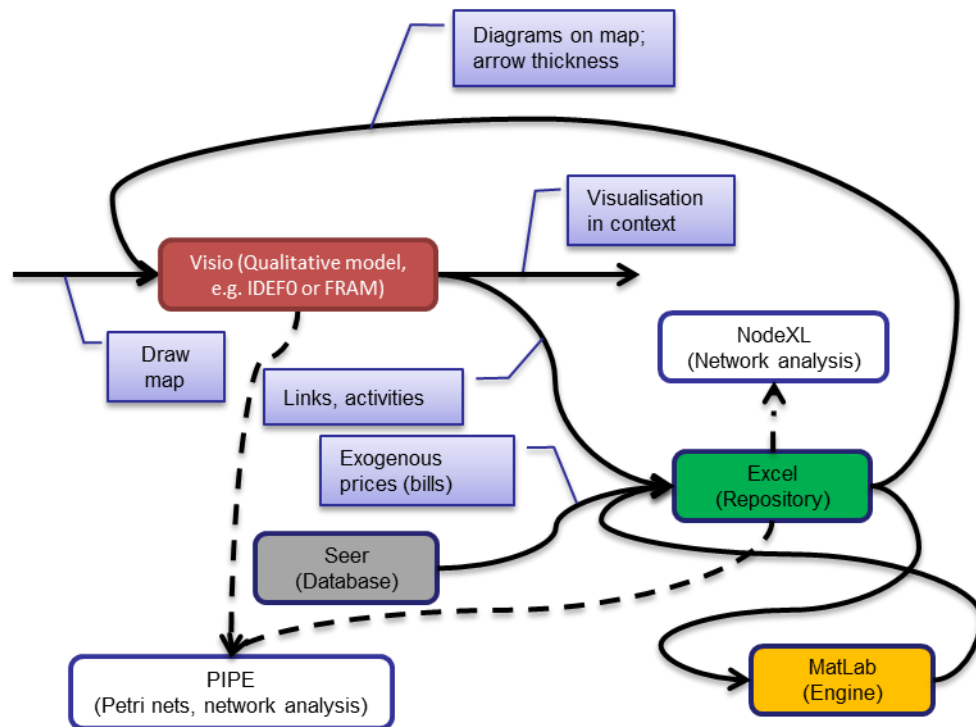


Figure 33 A proposed integration of the qualitative model (as IDEF0 or FRAM representation) with quantitative analysis tools

FRAM map that is then translated into matrices, as suggested by Settanni *et al.* (2013), for example in Microsoft Excel and a Petri net, for example in PIPE (Dingle *et al.*, 2009) for mathematical treatment. The cost attribution problem (Settanni *et al.*, 2014), the process of costing, is solved through a MatLab engine. Prices for externally acquired resources can be provided by commercial cost estimation software such as SEER by Galorath (www.galorath.com), or company internal databases. By feeding back the results from the MatLab engine into the qualitative model results can be shown in their context by means of diagrams or arrows of different thickness.

In addition to the costing process and Petri net analysis, matrices in Excel open the door to social network analysis for example with Node XL (<http://nodexl.codeplex.com>). Previous applications of social network analysis include supply chain analysis (Kim *et al.*, 2011a) and a combination of quantitative and qualitative data for the analysis of a firm's evolution (Coviello, 2005). Different approaches to social network analysis are discussed by Fuhse and Mützel (2011).

A topic that is covered by another strand in the CATA project is uncertainty. Accordingly, a detailed discussion of uncertainty is beyond the scope of this work. However, the approach adopted in this research challenges common ways of understanding specific categories of uncertainties such as ‘epistemic’ and ‘modelling’ uncertainty. Epistemic uncertainty is commonly referred to as uncertainty caused by the “lack of knowledge” about the “true” value of some elements of a model, e.g. a parameter (Kreye *et al.*, 2011). Similarly, ‘model uncertainty’ is used in uncertainty classification to describe the “inaccuracies” of a model in comparison to “reality” (Kreye *et al.*, 2011). Such views are quite opposed to the standpoint taken in this work that within socio-technical systems, the defensibility of a model, rather than its closeness to an objective truth matters. Hence, future work is needed to address the consequences for the quantitative modelling of uncertainty within socio-technical systems when acknowledging the inherent inability to gain complete and objective knowledge about them.

In addition to quantitative modelling, the qualitative analysis presented in this research can support the full application of the FRAM (Hollnagel, 2012) to understand how performance variability impacts on the conditions under which the PSS can reach the expected and desired outcome. Variability was observed in this research for example with respect to the meaningfulness of fault reports.

In general, a rigorous combination of quantitative and qualitative modelling can provide robust arguments for business process redesign, budgeting, risk assessment and contract negotiations. Discourse analysis might open the door to an improved understanding of PSS through analysing the flow of information and knowledge through documents, conversation and IT systems. Discourse analysis is not commonly used in PSS research. However, examples from the social sciences (Ashenden, 2005) and organisational research (Topp, 2000) show that in future work different strategies (Andersen, 2003) can be applied to address the role cost estimates play for power relations and the formation of knowledge within multi-organisational enterprises.

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APPENDIX

THE REPRESENTATION OF AN ADVANCED SERVICE DELIVERED BY A PRODUCT SERVICE SYSTEM

August 2014

Nils Elias Thenent, University of Bath

APPENDIX A: QUESTIONNAIRE

Knowledge Types

Explain concepts.

Personal information

- Job title
- Time in that job
- Responsibilities
- Day-to-day work

IDEF0 maps

Before asking the questions an agreement on the IDEF0 maps is sought.

- Do you recognize your work environment?
- Do you agree with the shown process map?
- Do you have suggestions for modifications?

Knowledge used, their quality, their sources

- What do you need to know about in your work?
- Which kind of knowledge, information and data (KID) do you rely on?
 - Where do you get them from (other processes on the map, and/or outside the map)?
 - Are there informal channels you use to acquire further or more detailed information?
 - How does their non-availability affect your work?
- Which set of skills/competences do you require?
- Could you describe what would make KID “good” for you?
 - Why?
 - To what extent you think the KID you have available is “good”? Why?
- Would you require more/other types of KID?
- What kind of improvement regarding the use and/or availability of KID would you like to see?

Process performance

- What performance indicators do you have in place to measure your process/work performance?
- How where they developed, who developed them?
- To what extent are you aware of the performance? Are the results visible?
- To what extent does the measurement of process performance affect the way you work? Why & how?
- To what extent do the KID/skills you have available affect your process/work performance?

Knowledge flow to other processes (show on the map, specify)

- What kind of data/information do you produce?
- Which of these do you provide to other processes?
- Which of these is exclusively produced for other processes?
- Do you know what these are used for and how useful they are for the other processes?
- What is the effort you spend in creating KID for other processes?
- How “good” do you think is the KID you supply to other processes?

Shift towards availability provision

- To what extent are you aware of a move towards availability provision for the MHDD/Typhoon?
- How has this move affected the KID you require?
- What is your knowledge about the contract in place? How do you know?

Link knowledge – resource consumption

- To what extent are you aware of the expenditure (monetary) of your process/work? How do you come to this awareness?
- What do you think is required to come up with a reasonable cost estimate for what you do?

AOB

- Is there anything else you would like to add (off record)?
- Any question you were expecting that was not asked?

End of Appendix A

APPENDIX B: INFORMED CONSENT FORM

Please consider this information carefully before deciding whether to participate in this research.

Purpose of the research

- To understand the sources and sinks of knowledge, information and data (KID) for delivering avionics availability.
- To identify the differences between required and available KID.
- To identify differences between official procedures and practice.
- To map the actual flow of KID between the processes involved.

What you will do in this research: You will participate in a one-to one interview. You will be asked several questions and to give your opinion on prepared process maps. Audio of the interview will be digitally recorded. You will not be asked to state your name on the recording.

Time required: The interview will take approximately ____ hours.

Follow-up: The interviewer may contact you after the interview for clarifications or follow-up questions. Please indicate how you would like to be contacted:

	Email	
	Phone	
	Please do not contact me after the interview	

Risks: Some of the questions may cause confusion due to terminological ambiguity. At any time you can ask for clarification if you are not sure about the meaning of a question. Some questions may be uncomfortable as they explicitly aim at identifying differences between official procedures and what is done in practice.

Benefits: The CATA project aims at developing a novel cost model to supports informed-decision making for performance-based offerings. Participating in this research will allow you to contribute with your views and experience, and enrich the research with insights that cannot be deduced in other ways.

Confidentiality: Your responses to the interview questions will be kept confidential. At no time will your actual identity be revealed. Your personal information will be protected; taking part in this study and the results from the study are not part of a performance review; your manager won't have access to the notes or data you help us gather. Your information will be rolled up with the rest of the data from the other study

participants. The audio recording will be transcribed and instead of referring to your name or position the data will be referenced with a number.

Data usage: The data you provide will be used for publications, such as journal articles and conference contributions, and the interviewer's PhD thesis. At no time will your name, or any information be used that would allow tracing particular statements back to you. All publications are subject to the agreements between the collaborating parties.

Participation and withdrawal: Your participation in this study is completely voluntary, and you may refuse to participate without penalty. Also, you may choose to withdraw at any time. You may withdraw by informing the interviewer that you no longer wish to participate (no questions will be asked). You may skip any question during the interview, but continue to participate in the rest of the study.

Contact the researcher: If you have any questions about this research please contact:

Nils Elias Thenent, Phone: 01225 38-5937, Email: N.E.Thenent@bath.ac.uk.

You may also contact the academic supervisor of this work:

Dr Linda Newnes, Phone: 01225 38-6291, Email: L.B.Newnes@bath.ac.uk.

Agreement:

The nature and purpose of this research have been sufficiently explained and I agree to participate in this study. I understand that I am free to withdraw at any time without incurring any penalty.

Name (print): _____

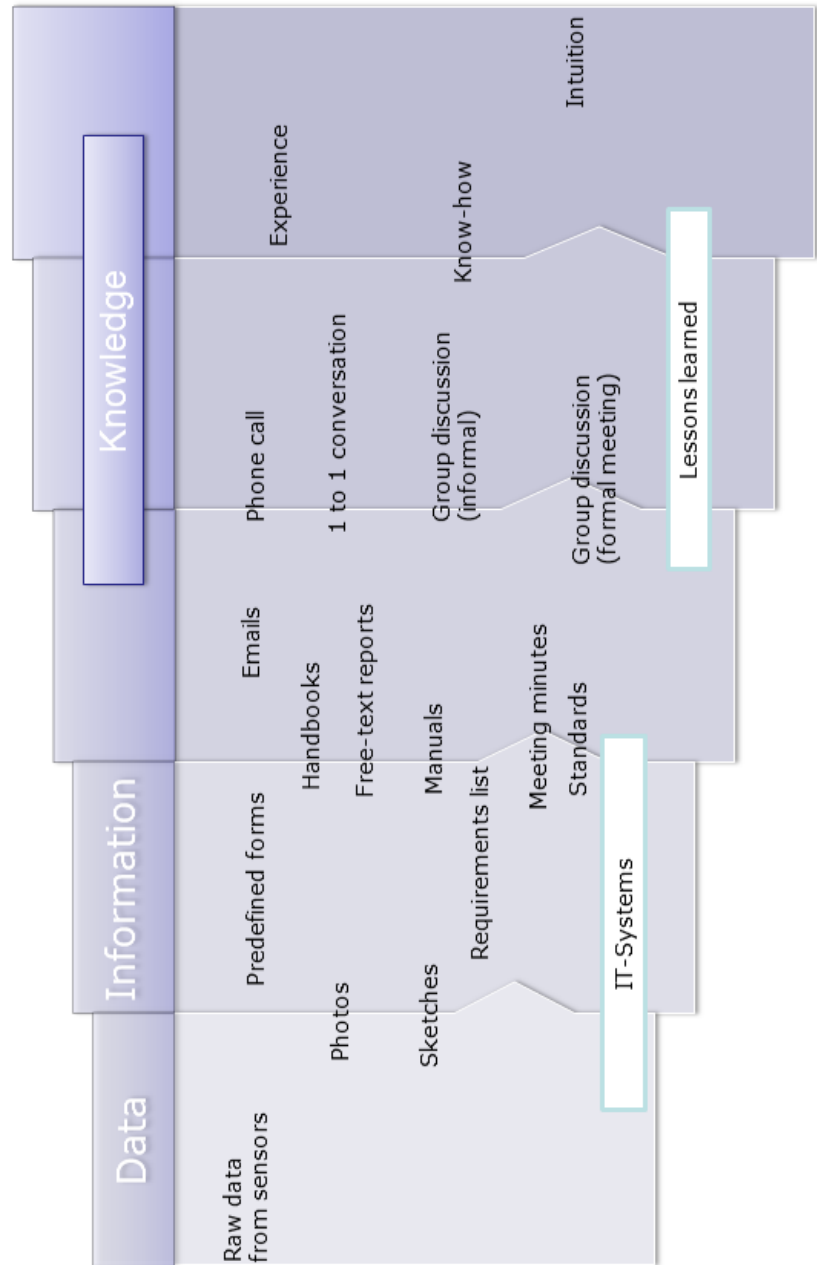
Signature: _____ Date: ____ - ____ - 2014

End of Appendix B

APPENDIX C: KNOWLEDGE CONCEPTS



Knowledge, Information, Data (KID)



APPENDIX D: IDEFO USED DURING INTERVIEWS

Pages 1 to 11

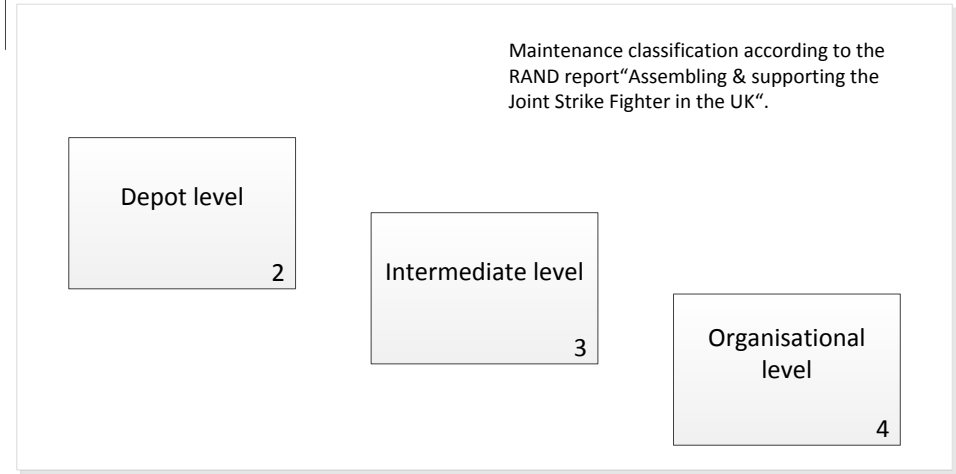
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Project: CATA	Author: NET	Revision #	Description	Date	Initials	X	Draft	Context
Notes: Common map V2	Date: 24.06.2013						Changes suggested	
							Publication	

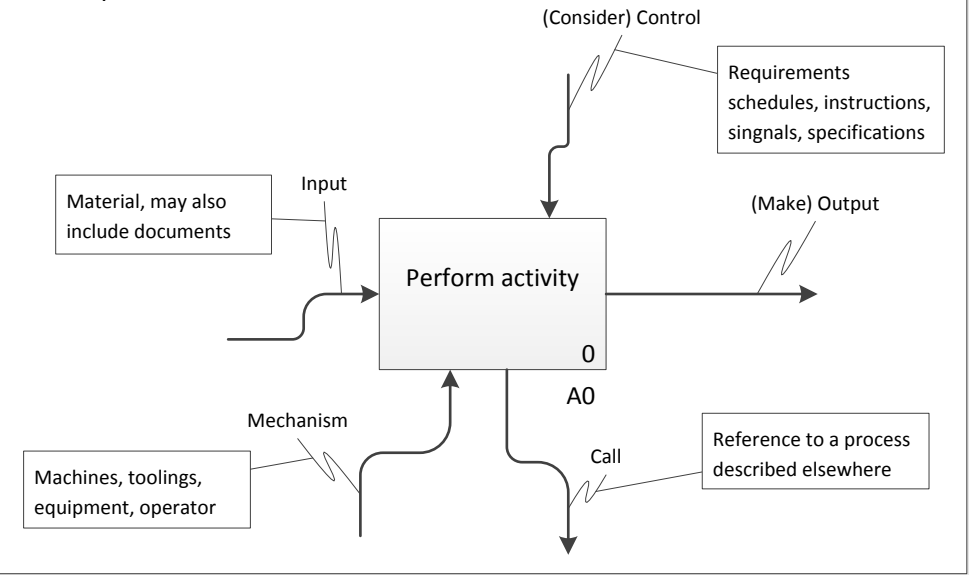
Terminology

Term	Description
Mission Readiness	All systems power-up as required by the planned mission. The A/C is ready to go.
MHDD Mission Readiness	At A/C start-up all three MHDDs power-up without showing “any” (?) malfunction.
Unserviceable	A state in which the unit cannot be installed on an A/C, be it due to a detected or undetected fault.

Maintenance levels

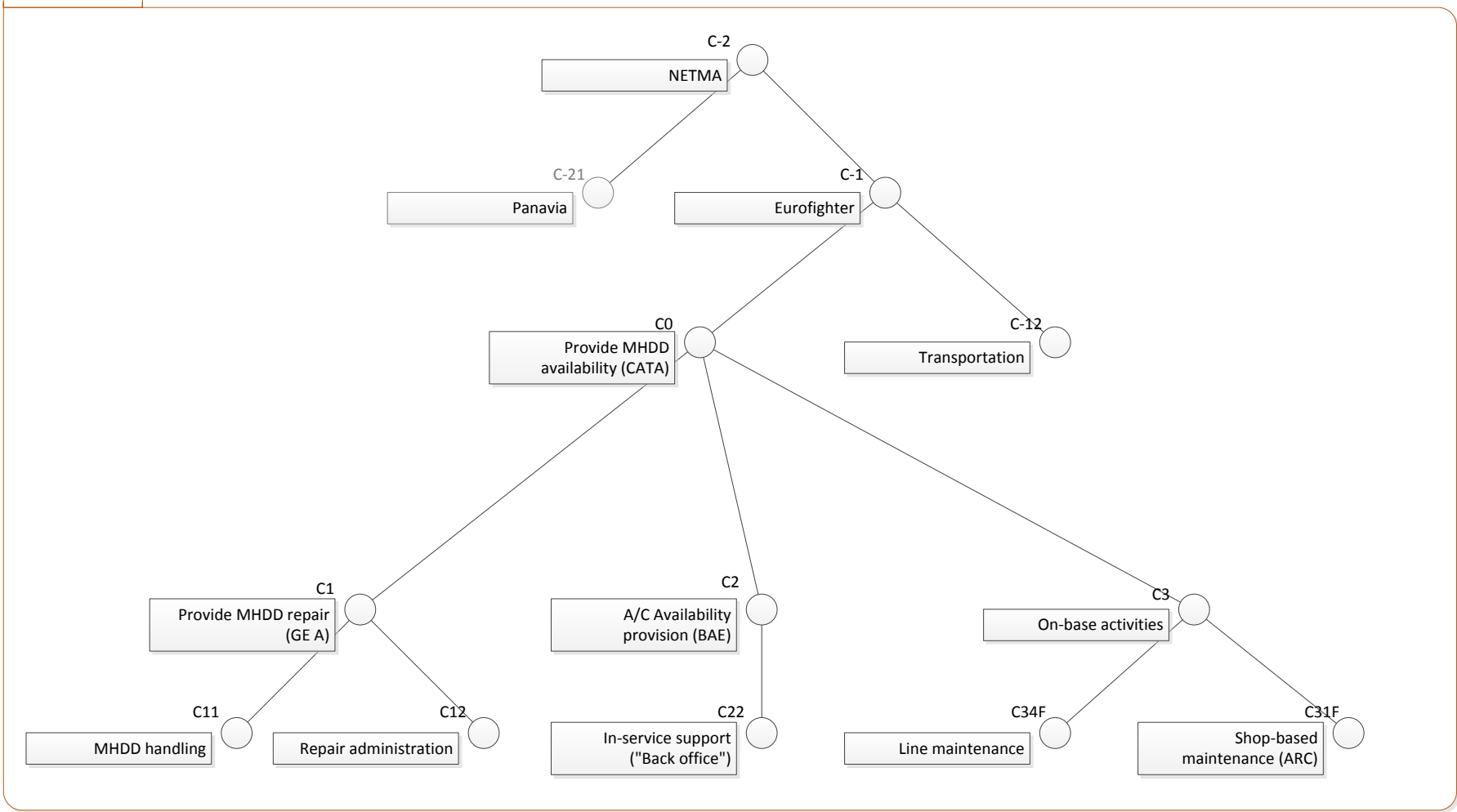


General process

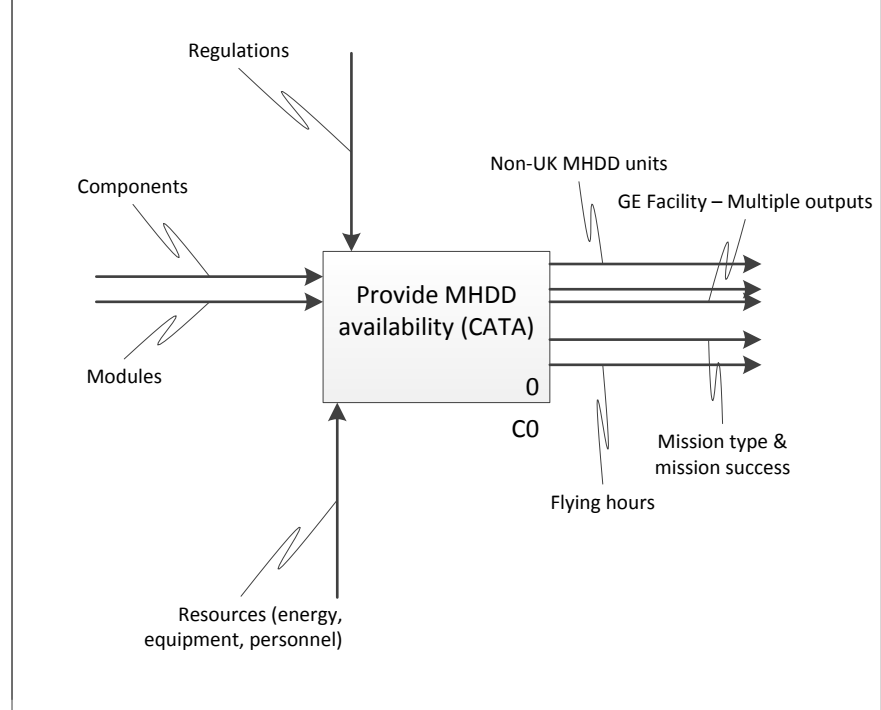


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CATA	NET	1	Revised node tree	17.07.13	NET		Changes suggested	
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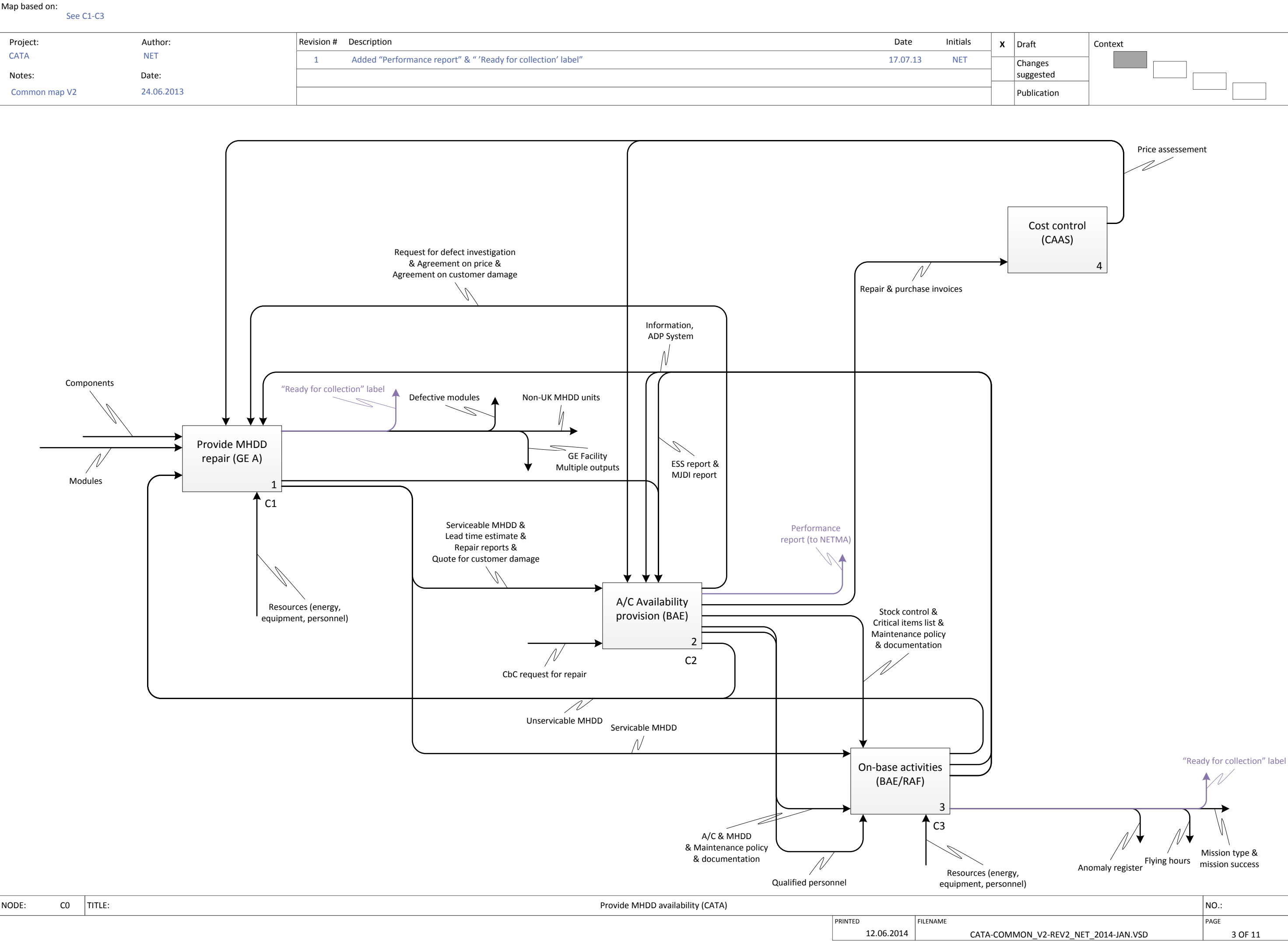
Node tree

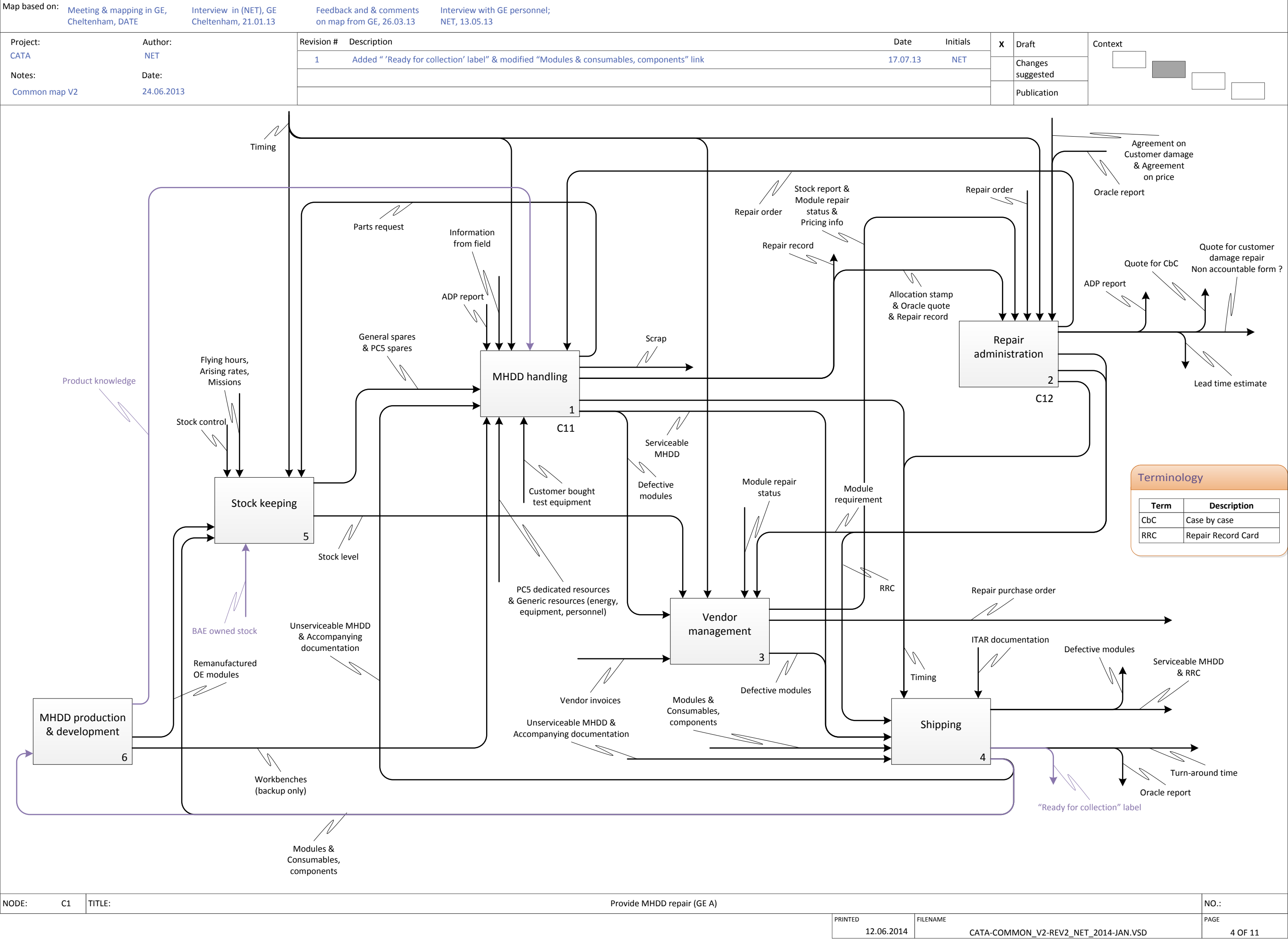


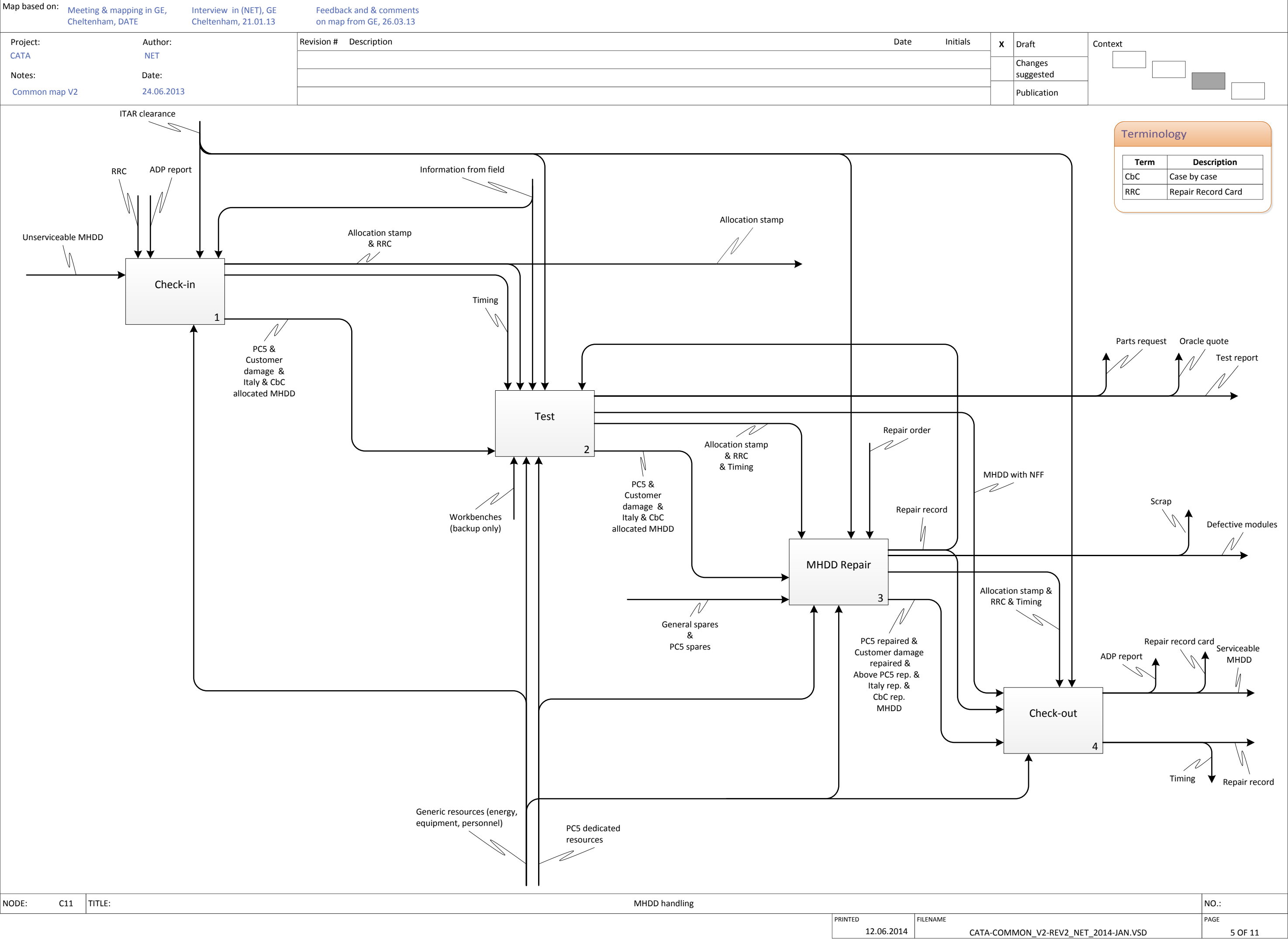
Context



NODE:	C-0	TITLE:	Cata research		NO.:
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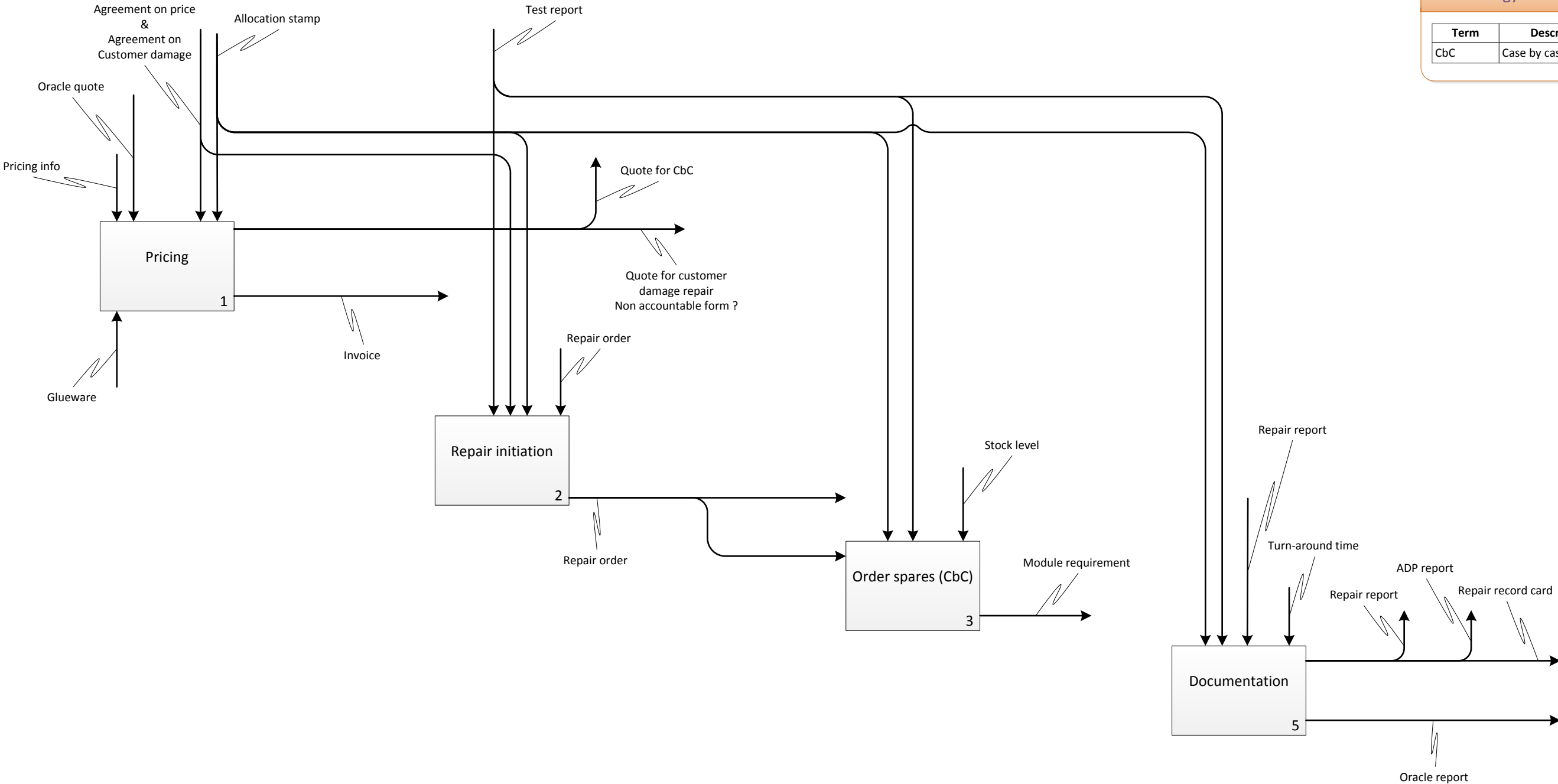




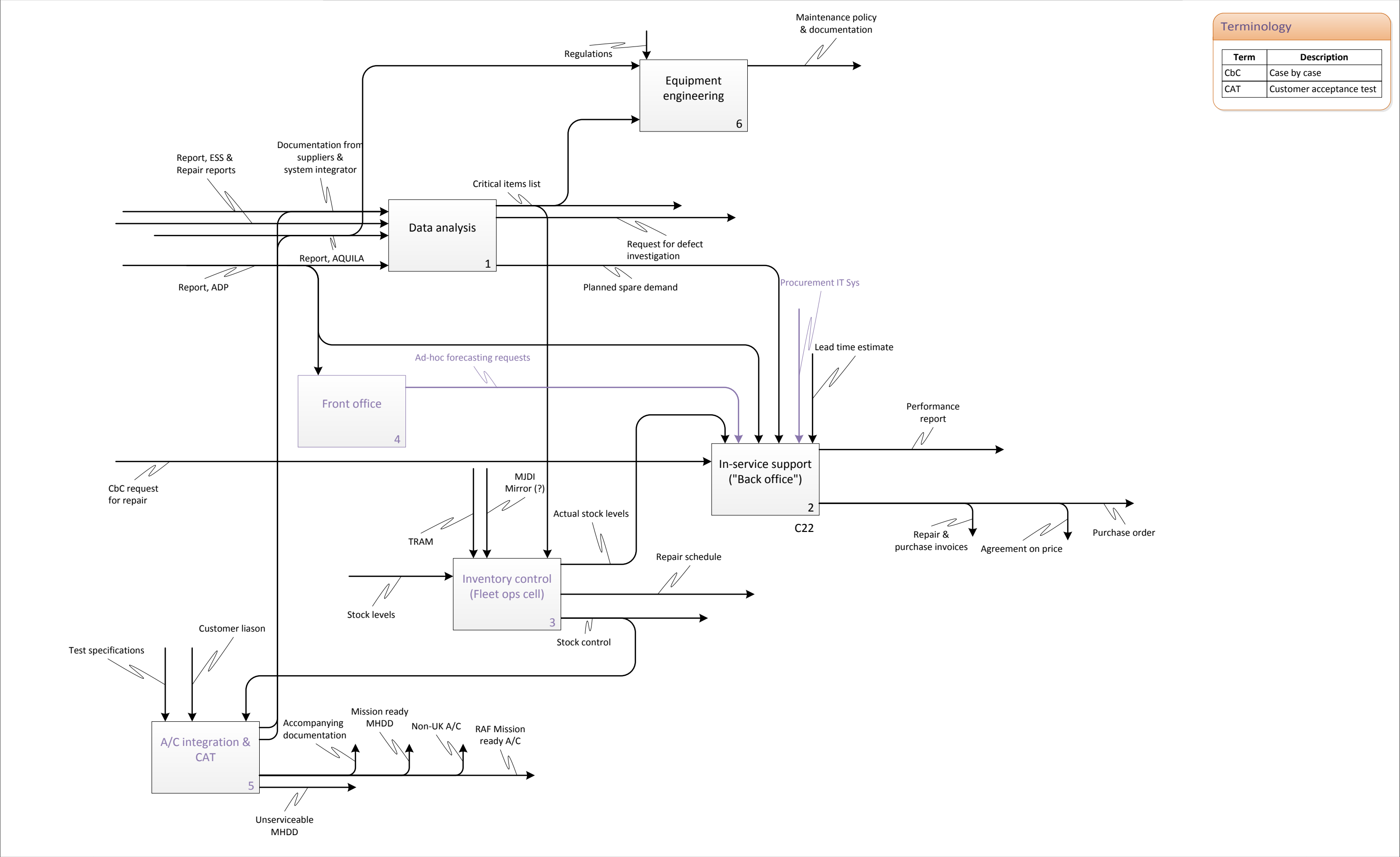
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CATA	NET							<div></div> <div></div> <div></div> <div></div>
Notes:	Date:						Changes suggested	
Common map V2	24.06.2013						Publication	

Terminology

Term	Description
CbC	Case by case



Project: CATA	Author: NET	Revision #	Description	Date	Initials	X	Draft	Context
		1	Renamed “3” & “5”, added control, added “4, Front Office”	13.01.14	NET			
Notes: Common map V2	Date: 24.06.2013						Changes suggested	
							Publication	



Map based on:

Meeting in BAE, Samlesbury, NET & ES, 23.03.13

Interviews in BAE, Samlesbury, NET, 10.07.13

Project:	Author:	Revision #	Description	Date	Initials	X	Draft	Context <div><div></div><div></div><div></div><div></div></div>
CATA	NET	1	Added sheet "C22"	17.07.13	NET		Changes suggested	
Notes:	Date:						Publication	
Common map V2	24.06.2013							

Procurement

1

Operations

2

Enhanced operations

3

Arising rate management

4

NODE:

C22

TITLE:

In-service support (Back office)

PRINTED

12.06.2014

FILENAME

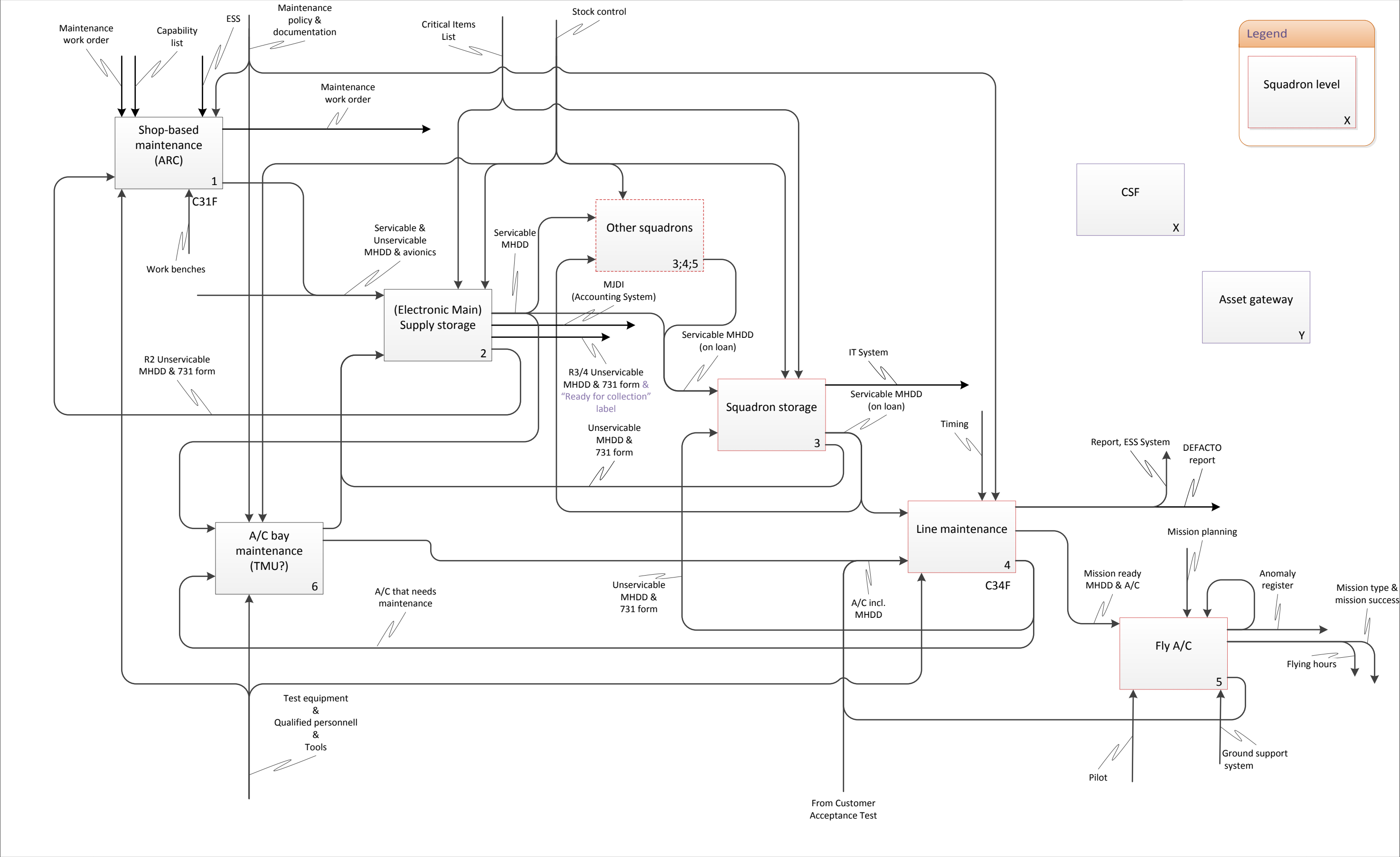
CATA-COMMON_V2-REV2_NET_2014-JAN.VSD

NO.:

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Project: CATA	Author: NET	Revision #	Description	Date	Initials	X	Draft	Context
		1	Added activities “X” & “Y” & “ ‘Ready for collection’ label”	17.07.13	NET			
Notes: Common map V2	Date: 24.06.2013						Changes suggested	
							Publication	



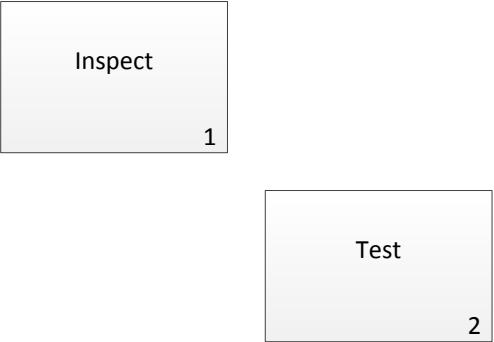
Map based on:

Discussion with LBN & MMN after their visit to Coningsby; NET & ES, 12.06.13

Project:	Author:	Revision #	Description	Date	Initials	X	Draft	Context
CATA	NET							<div></div>
Notes:	Date:						Changes suggested	<div></div>
Common map V2	24.06.2013						Publication	<div></div> <div></div> <div></div> <div></div>

For exposition only.

See ARC process map



Map based on:

Discussion with LBN & MMN after their visit to Coningsby; NET & ES, 12.06.13

Project:	Author:	Revision #	Description	Date	Initials	X	Draft	Context
CATA	NET							
Notes:	Date:						Changes suggested	
Common map V2	24.06.2013						Publication	

Pre-flight check

1

For exposition only.

Post-flight check

2

Servicing

3

Fault isolation & trouble shooting

4

Rectification

5

Release to service

6

NODE:

C34F

TITLE:

Line maintenance

PRINTED

12.06.2014

FILENAME

CATA-COMMON_V2-REV2_NET_2014-JAN.VSD

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NO.:

End of Appendix D

APPENDIX E: PAPER ABSTRACTS

Strategic Change

Special Issue: Servitization

Cutting cost in service systems: Are you running with scissors?

Nils Elias Thenent, Ettore Settanni, Glenn Parry, Yee Mey Goh, Linda B. Newnes

One sentence summary:

A rigorous link between the domains of cost estimation, systems theory and accident investigation reveals fundamental epistemological limitations of commonly employed cost models when dealing with the characteristics of systems, particularly service systems, which may hinder the ability to take appropriate action for cost reductions.

Key points:

- The ability to take action, in particular related to cost reductions in service systems, is strongly influenced by the understanding (epistemological assumptions) underlying a decision-support tool, in this case a cost estimate.
- There is a conflict in the underlying epistemological assumptions about what is and can be known in such a socio-technical system as a service system.
- A managerial perspective of cost estimation which neglects the essential characteristics of service systems may drive behaviour which is locally optimised but creates tension or failure at the system level.
- Cost cutting decisions that are based on a flawed understanding of the situation can lead to counter-intuitive outcomes for organisations; hence practical guidance is needed to help managers consciously consider the underlying epistemological assumptions in a given situation.

Maintenance Performance Measurement and Management 2013 conference

Maintenance within Product Service Systems: Is technical knowledge enough to link performance and cost?

Nils E Thenent, Ettore Settanni, Peter Sandborn and Linda B Newnes

Availability provision of high value assets is a Product Service System meant to overcome shortcomings of traditional business models. This article deals with the contribution of maintenance performance in this context, particularly in aerospace. The aim is to determine whether quantified knowledge about technical systems is sufficient to characterise successful maintenance, maintenance performance metrics and cost modelling. For this purpose the literature is reviewed to identify supporting propositions. Based on the evidences gathered, it is demonstrated that the type of knowledge applied for measuring maintenance performance and modelling the cost of maintenance match to a large extent. However, in this paper we demonstrate that this type of knowledge is insufficient to capture the conditions for successful maintenance. Finally, directions to address these shortcomings in future research are given.

ASME ESDA 2012

Know what you need to know: The role of technical knowledge in Product Service Systems

Nils E. Thenent, Ettore Settanni, Linda B. Newnes

An emerging trend in defence and aerospace is the move from manufacturing and selling products to providing the availability of a product-related function based on long term contractual agreements between the customer and the service provider. Therefore the concern of the manufacturer as a service provider shifts towards all means that are required to ensure the availability of the product related function. This ultimately imposes the adoption of a broader perspective on a complex system of interconnected and interdependent activities undertaken by a diverse network of stakeholders for the achievement of a common purpose. Nonetheless, a consistent and comprehensive way to represent such complex systems is not yet agreed upon in the literature. For the purpose of estimating the costs of a Product Service System (PSS) delivery, a consistent and common representation of products and services is a necessary precondition.

The focus of this paper is to contribute to the debate by proposing the use of knowledge as the underlying foundation for representing products, services and PSS.

Building upon inter-disciplinary literature, differing concepts of PSS are discussed, in order to identify recurring aspects and commonalities between product and service. While it could be recognised that technology represents such a common element, it is also recognised that differing definitions of technology do not facilitate the discussion about product, service, and PSS. Instead, evidence is found for the argument that applied knowledge can be seen as the underlying foundation for products, service and PSS. In this sense, knowledge is not considered as a single asset, but rather a composition of different kinds of knowledge.

The authors propose the application of knowledge to a process-based approach, which facilitates the representation of products and services by overcoming their distinction in a consistent way. While the composition of knowledge related to each process is a necessary precondition to enable the successful delivery of a PSS, it furthermore requires knowledge about integration of all process inputs, outputs and the processes' dynamics within a given environment. Herewith the focus shifts to the preconditions that enable the successful delivery of a PSS, such as available set of skills and underlying process understanding.

Discussing the role knowledge plays in current cost estimation methods it is found that – despite its importance – knowledge is not always clearly defined, and very often it is reduced to repository-based data retrieval systems.

The proposed knowledge-based process-orientated approach aims to facilitate investigating products, services, PSS, and the underlying production and delivery systems by representing them in a transparent and consistent way. While this is generally not bound to a particular type of analysis, the motivation originates from estimating the costs of a PSS delivery.

End of Appendix E